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Dialogic Activity Structures for Project-Based Learning Environments

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Activity structures such as classroom lessons and initiation–reply–evaluation sequences are important cultural tools that help students and teachers accomplish everyday activity, but they are not well adapted to open-ended inquiry conducted by students in small groups with teacher guidance. In this research, I identified alternative activity structures that better enable teachers to scaffold children's performance of open-ended projects involving artifact construction. A case study and discourse analysis from an earth science class show how dialogic activity structures at 2 time scales support students in learning the discipline of science. At the scale of a multiweek unit, an activity structure embodies aspects of science practice such as assembling data to support claims. At the scale of verbal exchanges, action negotiation dialogues, student questioning dialogues, and action feedback dialogues help the teacher to guide students in their work while requiring that students maintain agency. I discuss implications for the design of project-based learning environments.

Research on classroom discourse over the past 25 years has demonstrated that teacher–student interactions often follow similar patterns (e.g., Cazden, 2001; Lemke, 1990; Mehan, 1978, 1979; Nystrand, 1997; Sandoval, Daniszewski, Spillane, & Reiser, 1999). Most of this research has examined interaction patterns in "traditional" classroom arrangements characterized by teacher lectures and teacher-led, large-group discussions. Given the increasing importance of project-based and inquiry-based approaches in recent standards documents (e.g., National Research Council [NRC], 1996, 2000) and the volume of research on learning that advocates inquiry-based approaches (for summaries, see Bransford, Brown, & Cocking, 2000; Bruer, 1993), the dearth of research on classroom discourse in project-based classrooms is surprising. With this research, I aim to fill

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that gap along with related studies of educational practice informed by social constructivism (e.g., Cornelius & Herrenkohl, 2004/this issue; Herrenkohl & Guerra, 1998; Kolodner & Gray, 2003; Polman & Pea, 2001; Tabak & Baumgartner, 2004/this issue; Wegerif & Mercer, 2000).

Before describing the kinds of interaction patterns seen in project-based classes, a brief description of the more traditional patterns is warranted. For instance, a whole-group discussion about chemistry might look like the following:

1	Teacher:	This is a representation of the one S … orbital. S'pozed to be, of course,
2		three dimensional …. What two elements could be represented by such a
3		diagram? … Jennifer?
4	Jennifer:	Hydrogen and helium?
5	Teacher:	Hydrogen and helium. Hydrogen would have one electron
6		… somewhere in there, and helium would have …?
7		Student: *Two* electrons
8		Teacher: Two … (Lemke, 1990, p. 5)

Based on his observational studies of standard classroom "lessons," Mehan (1978, 1979; see also Cazden, 2001; Macbeth, 2003) would have described the preceding as two rounds of "initiation–reply–evaluation" (I–R–E). In such a sequence, the teacher initiates an episode by asking a question with a known answer, students reply with bids for correct responses, and the teacher evaluates[1] the responses and may initiate another round. Lemke (1990) conducted research following similar traditions in science classrooms and found the same basic discourse structure to be dominant, although he labeled it "triadic dialogue," or "question–answer–evaluation." In lines 2 through 3 and 6 of the preceding sequence, the teacher initiates the round with a question followed by a student answering in reply (lines 4 and 7) and the teacher providing at least tacit evaluation (lines 5–6 and 8).

Interaction and dialogue practices such as I–R–E in classrooms are part of complex cultural systems that when functioning smoothly allow the many participants to coordinate their actions while achieving multiple goals. It allows a teacher to simultaneously maintain a high degree of control in the classroom, probe students' current conceptual understandings, and orchestrate a description of those concepts using students' as well as the discipline's words to bring them toward grasping a set of clearly specified concepts. Such a pattern of discourse is well adapted for tradi-

[1]In other parts of the literature, the final step is sometimes referred to as teacher "feedback" (F)—making the sequence I–R–F—to stress that the final step may involve the teacher in extending as well as evaluating student responses (e.g., Edwards & Mercer, 1987; Wells, 1993).

tional "transmission-oriented" teaching (Pea, 1994) of curriculum relating to conceptual knowledge or of whole-group discussions intended to summarize an extended experience using a set of common terms of a discipline (Cazden, 2001; Edwards & Mercer, 1987). The I–R–E activity structure can be seen as a "cultural tool" (Polman & Pea, 2001; Wertsch, 1991, 1998) that is familiar to teachers from their own childhoods and familiar to most students after a couple of years in school. Thus, teachers and many students using I–R–E may understand well the norms of the speech genre (Bakhtin, 1986) they are using in interaction with one another: If it works well, they know what sorts of roles they are expected to play, what steps follow one another, what sorts of nuances indicate departure from the typical situation, and generally how one succeeds at participation.

There are several reasons why many educators are dissatisfied with the dominance of large-group I–R–E discourse patterns in classrooms. A growing body of research has shown that students from non-Euro-American cultures are less comfortable and often perform less well in classrooms dominated by I–R–E because this discourse pattern is mismatched to discourse patterns in their nonschool communities (e.g., Cazden, 2001; Rogoff, 1994). In addition, along with epistemological positions that equate learning and knowing with increased fluency of participation in the practices of a community (Brown & Campione, 1994; Lave & Wenger, 1991; Wertsch, 1991, 1998) comes a growing interest in enabling children to "speak mathematically" (Lampert, 1990) and talk scientifically (Lemke, 1990; Rosebery, Warren, & Conant, 1992; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001). Although some forms of whole-group discussion using the I–R–E model have been shown to help summarize a classroom group's diverse experiences according to the canonical terms of a discipline (Edwards & Mercer, 1987; Wells, 1993), such interactions must be preceded by more open-ended discourse patterns that draw out students' understandings prior to their mature development. To meet these goals, classrooms are increasingly being organized around small-group work, with the teacher acting as facilitator of projects or problems.

It is the latter kinds of classroom organization that I am interested in exploring. The bulk of the research on discourse in such "nontraditional lessons" (Cazden, 2001) has focused either on student–student discourse, in many cases at computers (e.g., Roschelle, 1992; Wegerif & Mercer, 2000), or on whole-class summative sessions (e.g., Brown & Campione, 1994; Engle & Conant, 2002; Sandoval et al., 1999). The lessons I am interested in are the increasingly prevalent contexts in which youth are working in groups with teacher guidance to conduct open-ended project inquiry such as that advocated by Dewey (e.g., 1901, 1938). Since Dewey (1901, 1938) and the progressive movement, there has been periodic interest in having students learn science by doing science (e.g., reforms of the 1960s beginning with Bruner, 1963; reforms of the 1990s such as Pea, 1993; Ruopp, Gal, Drayton, & Pfister, 1993). Project-based or inquiry-based approaches are advocated for meeting new standards that move beyond a focus on simply understanding concepts to also understanding the practices of a discipline (e.g., Krajcik, Czerniak, & Berger, 1998; NRC, 1996; O'Neill & Polman, 2004). In such classrooms, verbal interaction during group work is rarely based on the cultural tool of I–R–E because I–R–E does not have appropriate "affordances" (Norman, 1988). Specifically, I–R–E functions most commonly and easily when the instructional leader elicits known answers to specific questions about known concepts or facts or in some cases, processes that have already taken place; in open-ended projects, however, actions leading to the construction of artifacts are privileged over abstract concepts or specific facts, and there is not usually one correct path for action. Perhaps because the project approach is still relatively uncommon, teachers and their students do not have an obvious set of well-established speech genres for more "authentic questions" (Nystrand, 1997) to use as cultural tools for structuring the interactions between small groups of students and their teacher acting as a facilitator or guide. This fact can undermine the successful conduct of projects.

In this article, I explore activity structures for open-ended project inquiry conducted in small groups with teacher facilitation. In addition to the research cited previously, this work builds on research into other activity structures or participant structures that have been found to be effective scaffolds for learning such as "reciprocal teaching" (Palincsar & Brown, 1984) and "complex instruction" (Cohen, 1994). Within the domain of reading instruction, reciprocal teaching has been a highly successful means of introducing students and teachers to a new set of cultural tools for structuring their interactions in such a way as to facilitate learning metacognitive strategies expert readers use. Adaptations of complex instruction have been used to facilitate group work and science content learning among fourth graders (Herrenkohl & Guerra, 1998). However, activity structures for open-ended project inquiry are few and far between. In the following sections, I first delineate how the concept of "dialogic activity structures" can be useful at two levels of time scale for project-based teaching and learning and then analyze how some specific activity structures work within a project-based earth science class.

UNPACKING DIALOGIC ACTIVITY STRUCTURES AT TWO TIME SCALES: VERBAL EXCHANGES AND PROJECT UNITS

In various reports of classroom discourse, the terms *participant structure* (Herrenkohl & Guerra, 1998; Philips, 1972) and *activity structure* (Fuson & Smith, 1998; Lemke, 1990; Roth, McGinn, Woszczyna, & Boutonné, 1999; Sandoval et al., 1999) are used to describe in-class verbal interactions including norms, roles, responsibilities, physical arrangements, and dialogue sequences. In this article, I use the term activity structure because that term is often associated with a concern for the structure of verbal dialogue sequences, which I share.

The preceding studies of classroom discourse have tended to focus on generic speech acts that are repeated many times during a single class or group meeting. However, activity has a structure that is important at a more extended time scale as well. A single meeting or lesson as well as a set of meetings or a unit are often structured in meaningful ways to facilitate dialogic activity. Such longer term structures have been referred to in studies of classrooms and in the instructional design literature as "classroom lessons" (Mehan, 1979), task structures (Doyle, 1979), activity structures (Harris, 1998), or simply units. To give one example, Mehan described how multiple I–R–E sequences are put together to form topically related sets, and the latter are grouped to form a complete classroom lesson. One classroom lesson typically consists of opening sequences to begin the class period followed by topically related sets of sequences to cover instructional material and closing sequences that end the class period. Extending this model beyond 1 day, multiple class meetings can also have a structure: The typical 5-day sequence for science courses at the high school described was "lecture–lab–lecture–lab–exam." In problem-based and inquiry-based instruction, the overarching unit design often takes the form of an inquiry cycle (e.g., Kolodner, Gray, & Fasse, 2003; Schwartz, Lin, Brophy, & Bransford, 1999) or series of steps that build on one another (e.g., Jonassen, 1997).

All these cases of extended time scale activity structures can be characterized as having dialogic elements (Bakhtin, 1986; Wertsch, 1991) in which the students' and the teacher's voices and perspectives on classroom activity and the discipline under study interact with one another through speech acts as well as reference to and exchange of artifacts. To the extent that these longer term exchanges encourage learners to deal with how the discipline is practiced and arguments are made within it, the learners may develop according to Vygotsky's (1978) "general genetic law." According to this idea, learners first participate socially in the use of cultural tools and practices and then individually appropriate or "take up" the tools (Wertsch, 1991).

Following Lemke's (2000) terms *exchange*—dialogues lasting seconds to minutes—and *unit,* or thematic, functional curriculum units, I refer throughout the rest of this article to the shorter time-scale structures as "verbal exchange activity structures" and to the longer term structures as "project unit activity structures."

SETTING, DATA SOURCES, AND METHODS

In this study, I focused on dialogic activity structures found in a high school project-based science classroom. Elsewhere (Polman, 2000), I presented a more general description and case study of Rory Wagner's[2] earth science class, which was part of the Learning Through Collaborative Visualization (CoVis) project (Pea, 1993). CoVis was conceived as a means to create an extended learning community using the latest in computing and communications technology to support project-based science. My research focused on Wagner's class because he explored an even more open-ended version of the project approach than most teachers; Wagner's students conducted earth science projects of their own design. In practice, this meant that they participated in the formulation of a research question, the gathering of data to provide empirical evidence for addressing the question, analysis of those data, and reporting their findings. This kind of project-based science class was not the norm at the upper middle-class public suburban high school Wagner taught in; a few of his students had participated in extended group projects in a combined history and English course, but their other science classes consisted of lectures, demonstrations, and combinations of textbook work, worksheets, and what Wagner referred to as "cookbook" laboratories. The analysis I report here focuses on Wagner's period ½ Earth Science class during one 10-week project cycle beginning in the second quarter of the 1995 through 1996 school year.

Because the Earth Science class was not part of the standard science sequence at the school, more than half of the students expressed little interest in science. This group of 28 students consisted of 5 youth in 9th and 10th grades and 23 in 11th and 12th grades. As with the school as a whole, this class had less ethnic diversity than many U.S. public schools: 1 African American, 4 or 5 Jewish students, and 3 first-generation Americans, 1 each with parents from southeast Asia, the Middle East, and Eastern Europe.

During the 10-week project described following, there were 48 class meetings. Three days a week the class met for a 40-min period, and twice a week they met for a two-period block. I was a participant observer recording handwritten field notes focused on Wagner's actions and interactions for 17 of those class meetings and on 11 additional days supplemented handwritten notes with videotapes of Wagner interacting with students (audio captured with a wireless lavaliere microphone attached to the teacher) throughout the phases of the project (the project phases are described in the Science Project Unit Activity Structure section and shown in Figure 1). Those videotaped classroom interactions were transcribed, and handwritten field notes were entered into computer files for analysis. Additional data sources included teacher handouts and student-written artifacts marked up by the teacher as well as formal and informal interviews of both the teacher and selected focus students. The four formal interviews with Wagner and two with the students (one in the middle of the project, one following its completion) were recorded with audiotape and transcribed, whereas informal interviews with the teacher were recorded with handwritten notes and entered later into computer files for analysis.

[2]At his request, Rory Wagner's real name is used. All students' names are pseudonyms.

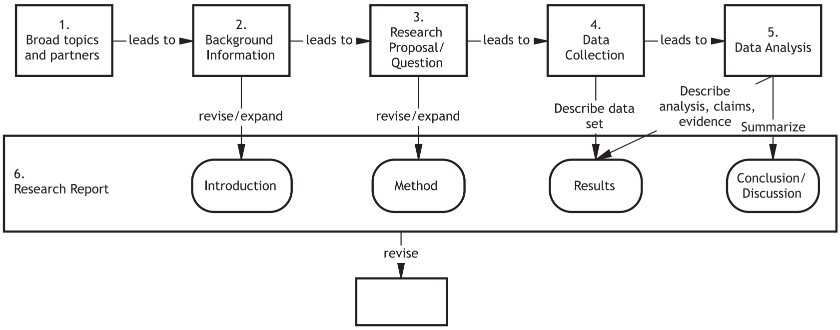

FIGURE 1 Project unit activity structure with relations between milestones.

Days when I did not directly observe in the classroom were usually summarized during informal debriefing phone interviews (14 days, leaving 6 days of class in the 10 weeks for which I have no records).

For this article, the data just described were reanalyzed to reveal the ways project unit and verbal exchange activity structures scaffolded students' accomplishment of projects. To do so, I conducted

1. A discourse analysis of students' exchanges with their teacher. For this analysis of exchanges according to verbal exchange structures, the transcripts of the seven class meetings recorded on video prior to project presentations were segmented into exchange episodes. The boundaries of segments were determined based on changes in conversational participants (e.g., Wagner finished talking with one student group, and another group approached him with a question) or topical shifts (e.g., transition from a discussion of constellations to a question about policies), sometimes marked by linguistic indicators of shift (e.g., an extended pause after a full stop and/or a marker such as "Now, …"). The segmented episodes were then coded exclusively by the three structural types described next and the traditional I–R–E structure.
2. A case study analysis of one student group's project activity from beginning to end focusing on activity structures using all the data sources including (a) two focus student interviews with one of the group members and (b) an analysis of "tracer" (Newman, Griffin, & Cole, 1984; Roth, 1996) terms related to aspects of science inquiry. Tracers are words or concepts that can be tracked as evidence of development, in this case, including notions such as empirical data, analysis, and evidence issues and scientific inscriptions, such as tables and graphs.

For both these analyses, QSR NUD*IST 4.0 qualitative analysis software was used to categorize data, isolate action and comments by actors and terms, and triangulate around terms and themes. Spreadsheets and graphs were used for simple quantitative analysis and presentation.

SCIENCE PROJECT UNIT ACTIVITY STRUCTURE

Rory Wagner commenced project work in his class each year after a quarter-long "lecture tour" of the earth sciences and other introductory activities. In the beginning of the project, he passed out two handouts including one titled "How to do an earth science project." Wagner focused the students' attention on the key issue of doing science and described an example of what he considered a good project. The students who did the project first decided on volcanoes and then specifically eruptions of the volcanoes, which are generally recorded and available data. They then decided to focus on one type of volcano and look for patterns in the time elapsed between eruptions. He stressed the narrowing process leading to a tractable inquiry. The students were not on their own in figuring out whether their projects were focused enough "to be doable"; Wagner was always available to help them.

The second of the two handouts Wagner distributed that day was titled "Project Milestones and Due Dates." The milestones he distributed were as follows:

1. Group and Topic—3 days.
2. Background Information—2 weeks.
3. Research Proposal—1 week.
4. Data Collection—2 weeks.
5. Data Analysis—1 week.
6. Complete Research Paper—1 week.
7. Presentation—1 week (see Figure 1 for an overview of this planned activity structure).

Wagner described each of the milestones, written or verbal artifacts delivered by the student groups, which subsequently received feedback from the teacher. Rather than the research paper being a separate assignment unrelated to the previous milestones, Wagner told the students "what you're going to be doing, is, you're going to be assembling parts of your paper as you go along." As shown in Figure 1, Steps 2 through 5 of the paper served as first drafts students revised and combined to create the draft of their final report.

The design of project units that Wagner developed for his class is powerful in part because of the synergy between the activity structure embodied in the milestone assignments and the artifact structure embodied in the format for the written report, which follows the basic "Introduction–Methods–Results–Discussion" genre of science research articles (Bazerman, 1988; O'Neill, 2001). Although the structure provides guidance, it has important differences from the more recipe-like laboratories students conducted in some other science classes. Many traditional laboratory steps give such detailed directions for every step that students can almost blindly follow them and "get the right results." Wagner's milestones, on the other hand, provide a framework that breaks the multiweek project activity down into more manageable steps, but the exact steps each student group should follow is not determined beforehand. There are no "right answers" in the sense intended by many traditional laboratories. Instead, there are multiple paths that students could follow to reach well-reasoned—or poorly reasoned—empirical conclusions about diverse topics in earth science. Along the steps of these paths, they turn in intermediate written artifacts that require them to "use complex thought" (Blumenfeld et al., 1991) rather than the more trivial fill-in-the-blanks and prompted questions found in traditional laboratories. Additionally, traditional laboratories involve the whole class in the same lockstep activity, whereas Wagner's students worked on different problems of their own design and choosing.

Like all activity structures, Wagner's milestone activity structure included dependencies between the parts. Some of the interdependence between parts of the activity, as well as the support Wagner provides throughout the activity, is mediated by these interim written artifacts. The milestone artifacts are "shared, critiquable externalizations of student knowledge" (Blumenfeld et al., 1991; Guzdial, 1995) that Wagner uses as occasions for feedback. Because the feedback is useful for later milestone artifacts, it has the opportunity to have more impact.

It is worth noting that Wagner developed and refined this series of interim milestones over several years. In his first implementation of milestones, Wagner asked students to immediately identify a research question. He found that students with little previous background were simply unable to come up with much beyond "basic information questions" (Scardamalia & Bereiter, 1991) such as "why does a comet revolve around the sun?" To come up with more ultimately productive "wonderment questions" such as "how does a comet's core size affect its tail size?" students needed a little more background on a topic area than they typically had at the onset. Therefore, Wagner adjusted the milestones such that Step 1 involved choosing a general topic area that students then had time to read up on and summarize in written Background Information reports. This allowed students to apply a cultural tool they already knew—the familiar model of "library research" or synthesis of established descriptions of phenomena (which some had learned in English or History). Finally, the presence of a separate information synthesis report early on emphasized the fact that students were expected to go on to do something different in subsequent milestones and the final report and presentation. This avoided the pitfall Wagner had seen in which students gathered and synthesized information about their topic but never answered empirical questions.

VERBAL EXCHANGE ACTIVITY STRUCTURES FOR PROJECT-BASED LEARNING ENVIRONMENTS

The project unit activity structure based on milestones provided occasions for multiple interactions in which student project groups and teacher exchanged ideas, negotiated meanings, provided feedback, and decided on actions. In my data sets, these interactions most frequently follow three patterns of verbal exchange activity structures particularly well-suited to project-based learning environments. I characterize these patterns as "action negotiation dialogues," "student questioning dialogues," and "action feedback dialogues."

Action negotiation dialogues begin with either a student approaching the teacher or the teacher approaching the student to inquire into the learners' plans. The first essential step is the students' bid to proceed with a subsequent action to move their project forward followed by the teacher's reply, a possibility for negotiation, and ending with assent on a course between student and teacher. For example, one day early in a project, the following exchange took place:

Student:	[sitting at her table] Hey, Mr. Wagner?
Wagner:	Yes
Student:	I have a question.
Wagner:	Yes [he walks over to her]
Student:	I'm doing, I think we're doing the extinction of dinosaurs
Wagner:	Mm hmm
Student:	And, uh, I don't know exactly where to look. Like, I have, like, there's a little information. Like that's all the information, that's on extinction.
Wagner:	Yeah. Well that's a good place to start, and then what you need to do is, look in *this* book [picking one up she has on the table], which should also be another good resource, and then let me get you a book or two from next door [that] might also help
Student:	OK.
Wagner:	OK?

The generic steps of this structure are shown following using the conventions that Lemke (1990) used, with optional steps shown in brackets:

[Student Bid to discuss *or* Teacher Query on proposed course]
Student Bid for action
Teacher Reply
[Negotiation: Student *or* Teacher Bids, Clarifications, Questions]
Student *and* Teacher Assent on course

Importantly, the structure enables the teacher and the students to negotiate both the meaning of their bids and their possible consequences for future action, with both students and teacher potentially contributing important details. Sometimes this negotiation is much like Schön's (1982) description of design professionals' "frame experiments," and it normally results in a tentative agreement on a path for next steps.

A second common verbal exchange activity structure in project-based learning environments was identified by Lemke (1990) but not found to be as common in traditional instruction as I have found it to be in this project-based environment. This is the student questioning dialogue, which takes the following form:

[Student bid to ask]
[Teacher nomination]
Student Question
Teacher Answer
[Teacher Check-up]
[Student Response] (Lemke, 1990, p. 52)

Student questioning dialogues are often informational or related to classroom procedures and logistics, such as the following:

Student: Do we get our paper back today?
Wagner: Yup, everybody gets their paper back today.

In both action negotiation dialogues and student questioning dialogues, the discussion is often both framed by the project unit activity structure and leading toward student instantiation of the upcoming milestone steps in some artifact. During the course of a project, the students also instantiate their understanding of the agreed on path by taking actions in their project, after which the teacher provides feedback on what they have done. This is the final activity structure I introduce, the action feedback dialogue. For example, Wagner approached some students investigating the astronomical basis of the zodiac:

[Wagner observes students perform a Web search on the term *zodiac*]

Wagner: You might also want to do a 'net search, on "constellations," though, instead of "zodiac."
Student: What?
Wagner: Constellations, 'cause the constellations are the things that make up the Zodiac.
Student: Yeah.

The generic form these exchange structures take is

Student Action or Report of Action
[Teacher Question]
[Student Clarification]
Teacher Feedback
[Student and Teacher Question, Clarification, Defense]

In contrast to the I–R–E structure, which is initiated and controlled by the teacher, it is worth noting that the three verbal exchange activity structures just described all begin with students. The fact that the students' actions or statement frame the content and goals of the exchange should help them maintain agency and integrate the conversational ideas into subsequent thought and action.

INCIDENCE OF VERBAL EXCHANGE ACTIVITY STRUCTURES ACROSS PROJECTS

As stated previously, I conducted an analysis of all exchanges between Wagner and the students during the seven videotaped sessions—one in each phase of the project unit activity structure. The talk of the teacher and the students with whom he conversed was segmented into exchanges separated by topical switches and/or changes in participants, and each exchange was categorized either as a teacher lecture (monologue), an I–R–E exchange, a student questioning dialogue, an action negotiation dialogue, or an action feedback dialogue. This resulted in a total of 206 verbal exchange segments, and the categorization of those exchanges across the project days is shown in Figure 2.

Figure 2 shows the occurrence of the various types of dialogue across the course of the project. There are a few instances of teacher lecture or monologue near the beginning of the project when Wagner was setting the stage and introducing the assignment. There were I–R–E exchanges on only 1 day during the project, as described in the case study following when Wagner held a whole-class brainstorming session on research question generation and refinement. Student questioning dialogues were present in significant numbers throughout the semester. These allowed students to raise both simple information questions ("Do we have the Web?"), more complex practice-oriented questions ("What is the method [section of the report]?"), or conceptual knowledge questions ("Do you know whether the Plesiosaur moved by rowing its flippers or flapping them like wings?"). After the 1st day, there was a steady flow of action feedback dialogues related to both artifacts students had shown to Wagner in their milestone assignments and actions that he observed them taking during class until the final stages after the data analysis when Wagner was providing a great deal of feedback on using data and inscriptions as evidence for claims. Finally, there were action negotiations throughout the project as well, with a greater number

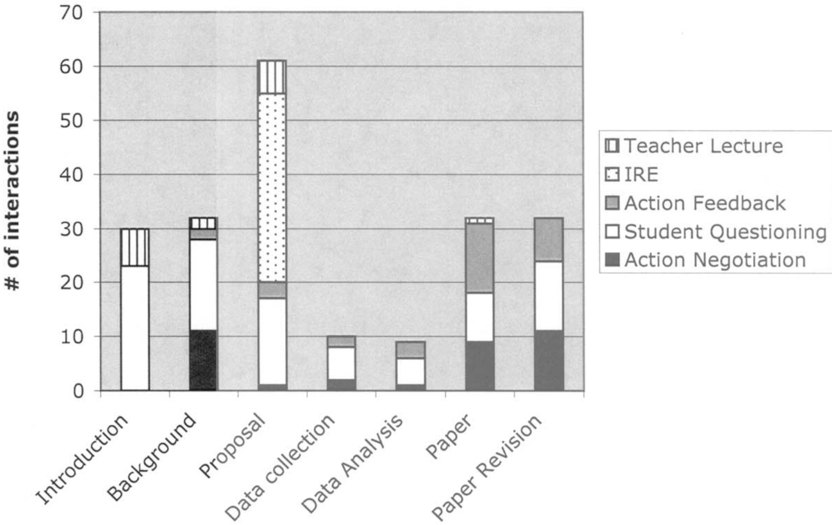

FIGURE 2 Numbers of verbal exchanges by type on 1 day in each project phase.

during the background phase when students were trying to figure out their overall direction and just what Wagner meant by a project anyway and in the latter stages when they needed to wrap up their projects and wanted to discuss how to accomplish that. As described elsewhere (Polman, 2000), the relatively low number of teacher–student interactions in the data collection and analysis phases of the project can be accounted for by the fact that Wagner depended largely on students to raise issues to enhance student ownership. Many students spent extended periods during this time talking among themselves or silently reading as they gathered and synthesized information and data before checking in with Wagner.

I next describe a student project that makes effective use of the two levels of activity structures to mediate their actions over the course of one inquiry. The case exemplifies how the project unit activity structure provided multiple occasions for productive verbal exchanges using the activity structures I've described, with each mutually constituting the meaning of the other.

CASE STUDY OF STUDENTS UTILIZING DIALOGIC ACTIVITY STRUCTURES FOR A SCIENCE PROJECT

Two students whom I call TJ and Dave conducted a project that illustrates how the dialogic activity structures described previously scaffold student action in the course of inquiry and simultaneously scaffold their learning of key elements of science inquiry as evidenced in their developing practices. I first summarize the case and then describe how the students' ideas and actions in the course of inquiry came into contact with the teacher's perspective.

Summary of Project Action

TJ and Dave were two experienced senior athletes who sat in the back corner of Wagner's classroom with some of their friends. They had done well in the first semester of the earth science class including lectures, an introduction to technology, and an open-notebook earth science content exam. They began their project by deciding to work together on the topic of hurricanes. For their research proposal, they decided to answer the question "Is there a preferred pattern of hurricane movement in the Northern Hemisphere?" With the help of a practicing scientist they communicated with by e-mail, they located a set of data in the form of maps from an Internet source showing yearly summaries of hurricane paths from 1880 to 1995. They learned to download and manipulate these images on the computer and turned in a set of them for their data collection milestone. For their data analysis, they began to combine maps of 4 years by tracing hurricane paths onto transparencies with colored markers. Although they combined these data for their data analysis milestone, they did not make any claims about the patterns other than the fact that those were "average years." For their paper's first draft, they changed their strategy and assembled individual maps for the years from 1985 to 1995, a composite map for all the years, and made the claim in their data analysis that "most of the recorded storms began in the Atlantic Ocean, east of the Caribbean, and made a C-like shape towards the United States and finished back east of the northern United States." In their conclusion, they also stated "the C-shape route is definitely the path of choice," but in neither the analysis nor the conclusion did they support these claims with specific reference to the data. Because most of the projects in the class needed more work, Wagner asked all the students to turn in a revised version of their paper, and in that version, Dave and TJ included the same raw data but made more specific claims about the locations and shapes of the hurricanes in their data set. They specifically stated that "the hurricanes were located between 45 N and 8 N and 45 W and 105 W," and showed this on a map with those boundaries marked and the starting points and ending points marked with dots. Their main findings about storm shapes were the following:

> We divided the hurricanes up into three categories, the common C-shape, the straight, and the irregular. There were a total of 83 storms recorded over the last eleven years. We found that most of the recorded storms began in the Atlantic Ocean, east of the Caribbean, and made a C-like shape towards the United States and finished back east of the northern United States. According to our data, 52% of the storms formed this common shape. The next most common path was formed by the irregular shape. These hurricanes can start

> anywhere from the middle of the Atlantic to the Gulf of Mexico. 26% of the storms since 1985 have performed the irregular shape. The remaining 22% of the storms formed what we called straights.

In addition, the youth included a pie graph showing the raw numbers and percentages of these three shapes. For their final project milestone, TJ and Dave prepared a PowerPoint® presentation summarizing their results and presented it to the whole class. This presentation highlighted their methods, data, and their findings about patterns in hurricane shape and location. The hurricane shape categories, raw numbers, and percentages from the written report were included. The location description was broken down into overall boundaries of all hurricanes as it had been in the written report, but the students also added a new map showing rectangular boundaries of the extent of starting and ending points separately—the northerly edge of the starting points and the southerly edge of the ending points overlapped.

Dave and TJ participated in—and I argue to some degree appropriated (Rosebery et al., 1992; Vygotsky, 1978; Wertsch, 1991)—several important practices of scientific inquiry that Wagner stressed through the course of their project. These include focusing in on a specific investigable issue, using appropriate empirical data to research questions, using empirical data as evidence to support claims, and more specifically using inscriptions such as maps and graphs as compact representations of data and phenomena. In the next sections, I trace the emergence and dialogic refinement of these notions through the occurrence of verbal exchanges and with the scaffolding of the project unit activity structure.

Focusing in on a Specific Issue

Bakhtin's (1981, 1986) notion of dialogism hinges on the notion that words (or other cultural tools such as practices and ideas) are "half-ours and half-someone else's" (Bakhtin, 1981, p. 345) and that one's own voice and the voices of others "interanimate" (Wertsch, 1991, 1998) with some degree of accenting from different uses and sometimes tension between uses. To show the microgenesis and ontogenesis (across a 2-month period) of TJ and Dave's inquiry practices, I focus on how the teacher and students introduce and take up ideas from one another. In this section, I look at how the students appropriated Wagner's ideas of focusing in on a specific issue.

Wagner set the landscape of acceptable topics as "anything in an Earth Science book" and illustrated that range in his first quarter lectures on geology, meteorology, oceanography, and astronomy. Dave said in an interview that he thought those lectures were useful because "you could see which sections you thought were interesting, [and] that would help in picking your topic." Wagner encouraged them in handouts and verbally to pick a topic that interested them. By Dave's account, he and TJ picked hurricanes on the basis of Wagner's lecture description and their interest in "destruction." They then borrowed books about weather and hurricanes from Wagner's collection in the classroom and also began to track down some hurricane resources on the Internet. They asked Wagner to help them save an image from the Web showing hurricane paths, which they included in their Background Information report. Their report contained a descriptive overview of what hurricanes are, how they arise, and the destruction they cause synthesized from information in two books and on two Web sites.

Up until that point, TJ and Dave's work, like that of the other students in the class, had been for the most part "traditional library research," with the possible exception of adding the Internet as a source. They had done mostly synthesis of known information, and they'd done it well. Next, they needed to, as Wagner put it, "focus it down [to] something where either you can do an experiment, or look for *data* that somebody else has collected, to try and answer a particular question." Because the whittling down to a research proposal was "a very hard step," Wagner held a whole-class brainstorming session on research questions using a photograph of a wolf pack from his office. The interactions that ensued between Wagner and the class as a whole group to brainstorm possible research questions followed the traditional I–R–E pattern:

Wagner:	If you're brainstorming about this picture, what are some questions that come to mind?
S1:	Who's leading the pack?
Wagner:	Who's leading the pack? That'd be a good question, yes.
S2:	Why do wolves travel in packs?
Wagner:	Why do wolves travel in packs? OK, another good question.

There were 17 R–E sequences following this initiation by Wagner. Many of the replies contained basic information questions, so Wagner then suggested they "take one of those questions … and try and get two more questions on *that* question." They tried that for 12 more I–R–E sequences, which instead resulted in more questions mostly unrelated to one another. Then a student questioning sequence occurred when someone asked "How would you know that [a wolf is a leader]?" Then there were three more I–R–E sequences and another student questioning sequence begun by the question "How do we write a six-page paper on that [a suggested question by Wagner]?" Thus, there were 35 I–R–E sequences in a row broken up by just two student questioning sequences. As stated in the introductory sections, the I–R–E verbal exchange activity structure is well adapted to large-group discussions in which the teacher has a highly normative goal. In this case, Wagner did not have one right answer in mind, but he wanted to guide the group of students, as a whole, toward questions that fit his criteria of appropriateness. For a question to be appropriate, he placed a high premium on its being focused on a specific issue, involving empirical data they could create or locate, and involving an analysis of some pattern or another in the data. Within the course of this series of exchanges, several students suggested questions about wolf packs, and then one suggested "How big are the packs?" Several turns later, Wagner picked up on that comment and said, "somebody was talking about sizes of packs; a project you could do would be 'what is the average size, or the size distribution of wolf packs in Minnesota, or North America?'"

Wagner summarized his goals in this conversation by telling students, "I'm gonna try and not let you down the wrong path to start with." He cautioned that they would run into trouble if they had a good question but could not find the information or data needed to address it. The next day on the blackboard, Wagner posted these additional suggestions on research proposals:

1) IT DOESN'T HAVE TO BE A "QUESTION"
2) THINK ABOUT
   A) HOW DOES IT WORK?
   B) WHY DOESN'T SOMETHING WORK?
   C) COMPARE "A" TO "B" (ALIKE/NOT ALIKE)
   D) HOW IS "A" RELATED TO "B"
   E) LOOK FOR "PATTERNS"
   F) LOOK FOR "ANOMALIES"

Partway through class, TJ and Dave had generated a list of questions, which they showed to Wagner. An action negotiation dialogue between Dave and Wagner ensued:

Dave: Mr. Wagner, we have this list of questions now. Should we develop one of them into a proposal?

Wagner: There are 2 things to do. You can try and make one of the questions into one of those [points to board, showing list in Table 1] kinds of things. [Wagner reads their list] I don't know. Actually, you've got some good things here. "What are the patterns?" is a good one. Like, what are the patterns over time?

Dave: Yeah, there are hurricanes every year, but this year it seems like there's more.

Wagner: And why is that? You could look at how many there were every year, and it might expand to how many at what time of year. What about the sizes of them over time, or in any particular season? … For starters, I'd say the patterns one is the best, and also this one is kind of related, but if one of the others is related, it could become relevant too.

Dave: OK

Wagner: I hope I helped

In the preceding action negotiation dialogue, the student initiated the exchange with a bid to proceed on the project by developing one of the questions further. I read Dave's term "develop" as taking up Wagner's notion from the previous day's whole-group discussion of focusing further and taking one question and further refining it. The teacher replied by referring, when he said "those kinds of things," to the list he had on the board. As he read the boys' list, Wagner noticed the one using the term "patterns," which he had used verbally in class and put on the board as a category of research proposal question. Wagner positively evaluated the pattern question by "revoicing" (O'Connor & Michaels, 1996) it, first with simple repetition in reported speech attributed to the students and second with a reconceptualization (Cazden, 2001) or refinement to include time, either within or across years. It is not clear, however, from the students' inclusion of this question on their list the extent to which they were here "borrowing" (Bakhtin, 1981) Wagner's term because of his potentially authoritative position as teacher in the class with little opportunity or expectation that they would interanimate their voices with his or whether it made sense to them from their own perspective. Rather than having his students take his suggestion as authoritative in the Bakhtinian sense, Wagner sought to encourage the students to have "internally persuasive dialogue" with his stance by allowing them to choose among options he presented and to refine his ideas because as he told them, "[they] are the experts on [their] topic" after doing their background research. In another project, for instance, Wagner thought that students choosing among research proposals regarding wooly mammoths would reach interesting territory if they compared and contrasted the wooly mammoth and the elephant, two evolutionarily unrelated creatures who filled similar ecological niches. Wagner liked this better than the path they chose, exploring the reason for the wooly mammoth's extinction, but he did not hold that against them. In this case, however, Dave and TJ assented with no initial refinement to Wagner's suggestion in this action negotiation. Yet later, they refined it, as I show, and these initial statements by Wagner and their mutual participation in an action negotiation dialogue created heuristics for subsequent activity (Holland, Lachicotte, Skinner, & Cain, 1998) that signified intersubjectivity (Rommetveit, 1979) among the students and teacher.

As evidence that Dave appropriated some of Wagner's ideas about focusing in on a specific issue and found it internally persuasive, consider some of Dave's comments in an out-of-class interview. Dave's summary of their project included this description:

> We started with just hurricanes as our general topic, and then we started getting information, and then more and more stuff we got was, you know, we got North America, and we got pictures and maps of hurricanes in North America and the Northern Hemisphere … So we narrowed it down to pre-

> ferred paths of hurricanes in North America. And, so what we've been doing is getting maps from a bunch of different years. You know, we got one from 1899, and 1992 and '93, '94, '95. You know, we found a place where you can get all these maps, so we can just compare the different tracks and the different patterns of the hurricanes over time, to see if there's any different patterns.

Just as Wagner had suggested narrowing down from a general concern with wolves, to wolf packs, to a specific focus on wolf packs in North America or even just Minnesota, Dave and TJ focused in on hurricanes "in the Northern Hemisphere." Similarly, Dave and TJ chose an initial topic of avalanches for their next project after the one described here and then focused specifically on avalanches in the state of Colorado and proposed the specific question: "Does annual snowfall in Colorado ski resorts have a direct effect on the number of avalanches they received over the past ten years?" In the action negotiation dialogue shown previously, Wagner suggested patterns of hurricanes over time, which Dave took up, but further focused on tracks rather than other possible features (e.g., intensity, duration).

In addition, when Dave contrasted his earth science research project with the interdisciplinary history-English project he had done the previous year, he said

> One of our projects was like, we did a project on "The 80's." You do a project, we had to put together a whole … we made up like a TV Guide and we did like a bunch of different shows, and we put in all these different themes and stuff. And so, I mean, there was a lot of leeway with what you could do. In this [earth science class] you have, you know, a direct topic. So.

When I tentatively revoiced Dave's last comment as meaning in earth science class "you end up with something in a much smaller an area than the 80s," he said "Yeah."

In this section, I have shown how Wagner presented the notion of focusing a research project through traditional lectures and I–R–E exchanges but then worked to engage students in the instantiation of such practices through the action negotiation verbal exchange. This negotiation of the students' research proposal action was framed by the project unit activity structure, which reified the notion that the research move beyond "standard library" synthesis research of others' findings by making clear that there was a lot more project to do after synthesizing the background research. We see in both the students' subsequent project actions and interview comments evidence of appropriation of these ideas, which originated with the teacher, in new contexts delineated by decisions the student had made.

Locating and Using Appropriate Empirical Data to Research a Question

As mentioned previously, Wagner had verbally encouraged the students to focus their projects "into something that you actually can do some research on, something where either you can do an experiment, or look for *data* that somebody else has collected, to try and answer a particular question that you have." In addition, on the "How to do an earth science project" handout, Wagner had written,"you collect and analyze your data to answer your question … This can either be data which you would collect by observation or experimentation, or by collecting and using someone else's data." Dave and TJ indeed ended up finding some available hurricane data that someone else had collected with the help of a telementor (Harris, 1998; O'Neill, 2001). Wagner had recruited their telementor through the Internet newsgroup "sci.geo.meteorology" with a post requesting "mentors" who would assist his students on their projects "not by giving answers and spending lots of time explaining basics, but by asking questions" or providing "insight to data collection or interpretation."

Near completion of their Background Information milestone, TJ and Dave had e-mailed their assigned mentor, a hurricane scientist at the National Hurricane Center, asking for any suggestions or help he might have for their project. The day before giving the list of potential proposals to Wagner (mentioned in the previous section), they received an e-mail response, and this student questioning dialog happened:

> Dave: Our mentor asked if we have the World Wide Web. Should we tell him yeah?
> Wagner: Yeah. That's what we do with Netscape.
> Dave: He said he could share some stuff with us if we had it.
> Wagner: Good.

Earlier in the semester, the students had learned to use Netscape on their computers, but the term *the World Wide Web* was not yet common, and Dave did not recognize it (his puzzlement over the term, as opposed to concern over whether to respond, makes this sequence a student question rather than an action negotiation). Wagner's simple clarification allowed them to respond to their mentor who then e-mailed them a number of URLs, including one that led to the students' data source with hurricane path images. The students explored the Web pages he told them about, and they followed links from these pages to eventually locate a historical data set of yearly hurricane activity (for similar data, see National Oceanic and Atmospheric Administration Coastal Services Center, 2003). They printed one of these out, and a short action feedback dialogue ensued:

> Dave: Mr. Wagner, look what we found in Netscape. [points to a map of all hurricane paths in 1995 on their computer]

Wagner: That's a good piece of data
Dave: That's what the guy [the telementor] told us to do
S3: You guys are lucky
Wagner: So that's data on hurricanes in 1995. Now try to get some other years.

This, like many other verbal exchanges during that period, focused on data, which Wagner worked to distinguish from information that was not somehow categorical, combinable, or numeric. "Good" data like Dave and TJ's could be analyzed, whereas information could only be synthesized or restated. Dave and TJ were excited about all the maps and pictures they had found, so they decided to propose a research question on the paths of hurricanes shown in the maps. Specifically, they proposed answering "Is there a preferred pattern of hurricane movement in the Northern Hemisphere?" by establishing patterns in data from the Web site.

As described previously, the students generated the initial idea of examining patterns of hurricanes after the brainstorming session and their Background Information report, probably based on Wagner's suggestion of that kind of question; Wagner liked the idea and added the prospect of looking for patterns over some period of time in an action negotiation dialogue; and the students refined their idea to focus on the patterns of hurricane movement after finding images showing the paths of hurricanes with the help of their mentor and a student questioning dialogue as well as an action feedback dialogue with their teacher.

Evidence from other sources indicates that Dave, TJ, and their fellow students in Wagner's class strongly appropriated this notion of using empirical data consisting of numbers and images beyond the project cycle described here. Like many of their fellow students, Dave and TJ used data sets found on the Internet in their subsequent projects; in their next project, they used a Web site that reported annual snowfall and incidence of avalanches to explore the question, "Does annual snowfall in Colorado ski resorts have a direct effect on the number of avalanches they received over the past ten years?" In addition, when asked on a task requiring transfer of inquiry planning practices, Wagner's students as a whole increased significantly on their inclusion of specific empirical data in project plans (O'Neill & Polman, 2004).

Using Empirical Data as Evidence to Support Claims

Dave and TJ moved into the next phase of the project, gathering the information and data—in this case, images of hurricane paths off the Web—they needed to answer their question. Wagner told me in a phone interview "they've got clumps of data, not every year … They were working on maps and trying to figure out how to compare the paths. They came up with the idea of transparencies. TJ did." The Web site the students had located showed all the hurricanes for each year on one map, so they were searching for ways to compare and contrast maps from multiple years because their question related to hurricane patterns over multiple years. I do not have an observational record of their interaction, but it is likely that the youth and the teacher discussed this idea of using transparencies in an action negotiation or action feedback dialogue. For their data collection milestone, they turned in the set of hurricane path maps on transparencies from 1899, 1992, 1993, 1994, and 1995. As mentioned previously, Wagner talked about data frequently in class and specifically about how you use data to "prove" things. In the "How to do an earth science project" handout, Wagner had also written, "basically you are going to be looking at 'how do things work?' What proof (data) can you find?"

As they moved into the Data Analysis phase of their project, Dave initiated an action negotiation dialogue about what they should do next, and Wagner replied, "you should compare them somehow … you have the data, but what does it say?" Through the processes of "poking, sifting, and organizing" all those images and tracing their paths, it turned out that the students developed a definite impression of what the data "said" about how hurricane paths tend to be shaped and located. In an interview outside of class on the day they turned in their Data Analysis milestone, I asked Dave whether they were finding any patterns. Dave said, "most of them … start southeast of Florida and east of the Caribbean, and then kind of like they're really making a swoop up towards the United States, and then they die in the Atlantic; they make a little semicircle."

On that same day, the students had barely gotten the Data Analysis assignment together by the end of class and hurriedly composed an ad hoc "conclusion" in the e-mail message to which they attached the map images. Wagner looked over these assignments over their winter break, and on the 1st day returned feedback. The teacher was unsatisfied with their use of the data to support conclusions and told me before class he thought they were falling into the common pitfall he'd seen of "generalizing a conclusion from inspection." Wagner had a discussion with them about their claim that the years they had chosen were "average years." The action feedback dialogue was as follows:

Wagner: How did you figure out they were average years?

TJ: We looked at maps

Wagner: You have to prove it to me, or the reader, that these are average years. You can't just say it. You can say you have 4 apples, but if 3 are red and one is green, you have to convince me they are all apples …

How do you define the average year? Maybe with frequency? Someone in another class is looking at the number of hurricanes per year. There's also the number of storms, tropical storms, and the number of each hurricane category … There were 21 hurricanes last year. Other years had 5, 8, 10, and 11 … But maybe the average is not in terms of numbers, maybe it's in terms of paths. Maybe you can see which years are average, then use those.

In this conversation, Wagner pushed the students to refrain from making claims unless they could back them up with specific reference to the data. When he generated the two possibilities that average years could be determined by the number of hurricanes or by the paths, separated by the qualifier "but maybe," Wagner was also modeling the scientific practice of generating alternative hypotheses with means of disconfirming each. In this case, the discussion did not lead to further analysis of what constituted an average year because the students did not find that they could support that claim. They did need to look at multiple years, so rather than choosing a discontinuous set that needed to be defended somehow, Wagner suggested they use the sample from 1985 through 1995 to establish some pattern.

The action feedback dialogue sequence and the particular exemplar just shown is heavily normative in ways similar to and different from I–R–E sequences. On one hand, the teacher generally responded to a student action in this way when he had clear expectations as in this case about particular norms of science. This is similar to the ways teachers have particular conceptual material they wish to check and/or convey through I–R–E. On the other hand, his feedback based on students' actions is normative to expectations for the practices that the students are carrying out in the project. In the case of Wagner's Earth Science class, student actions were judged against the norms of science inquiry as their teacher interpreted them. Having conducted master's-level geology research, Wagner was a "legitimate peripheral participant" in the science research community of practice (Lave & Wenger, 1991). Thus, Wagner's feedback on formulating focused empirical questions and carrying out analyses provided opportunities for students to appropriate expert science practices (Polman & Pea, 2001).

By the end of that week after winter break, the students were supposed to turn in their full paper reporting on the entire research project and findings. With a day to go before the research report was due, Dave and TJ had a long action negotiation dialogue with Wagner trying to solidify their data analysis techniques. Wagner asked them what the general pattern of hurricanes was, and TJ drew for him the swooping shape Dave had described to me previously. As they continued to look over the data, Wagner noticed that not all the hurricanes followed the C-shaped path the boys had described. Some were straighter than the standard C, and others appeared erratic. Wagner then suggested they could devise a categorization scheme for the shapes of paths. They could go back to each year in their set and put a morphological name on each hurricane, count up the frequencies of each shape, and calculate the percentages. Wagner described how he had done similar categorization schemes in his geological inquiry at the master's level. He told them he believed that such an analysis would be "valuable." Not surprisingly, Dave and TJ's incorporation of these ideas was only cursory in the report they turned in on time the next day. For this report, the students included a title page and abstract and then a revision of their Background Information milestone assignment as the Introduction section followed by a one paragraph Data Analysis section including their maps of separate years and one showing all the maps overlaid on one another, a six-line conclusion, and finally literature cited. Like most of the other reports, Wagner found Dave and TJ's report riddled with problems.

As mentioned previously, Wagner decided to allow all the students to turn in a revised report because so many needed improvements. Wagner had included extensive written feedback on all the reports on the front page, in the margins, and on the backs of pages. On the front cover, he'd commended their "outstanding effort" in writing, and listed their strengths ("excellent data collection and manipulation") and weaknesses ("no method," weak but fixable data analysis, lack of support for conclusions). Throughout the text, Wagner interspersed minor editing feedback such as grammar and punctuation, five short questions such "What is the interaction between the cooler and the warmer air?" and two full pages of written commentary including feedback and suggestions on the data analysis and conclusion. Wagner's written feedback on the report saying there was "No 'Method'" spurred this occasion of a student questioning dialogue:

TJ: So is the method, you just recount everything, how you've done things?
Wagner: How you did what you did. How you did what you did, and what you did.
TJ: I thought that was the abstract.
Wagner: No, the abstract-
Julie: It's a summary of that
Wagner: What she said.

Based on that written and oral feedback, TJ and Dave corrected their omission of a Method section, but their improvement in using data as evidence to support claims was far more important. The students had made some clear claims based on their sense about the hurricane paths. They'd made three references to the C-shape path in the report, saying that "most of the recorded storms … made a C-like shape," that that shape "was very evident," and that it was "definitely the path of choice." In his feedback, Wagner wrote

> You have lots of good data to analyze. But, you just packaged all the data into a pile … and you make statements in this analysis section *without* referring to the data once. You *can't* do that. In *this* statement [that "most of the storms made a C-like shape"], you need to *show/prove* this is true. Which diagrams show this? Of the total # of storms over this 11 yr. pd., exactly how many (and then, what %) of the storms had this 'C-shape' path?

Thus, Wagner referred in his written feedback to the action negotiation dialogue they had had with him prior to turning in the report when they had told him of the

C-shape, and he had pointed out that they could categorize each storm's shape and count them. He reiterated in writing that he saw three other shapes besides a standard C: a straight C, a straight, and an irregular. He wrote "If you classified each storm as one of these (or make your own categories), you could get a more detailed analysis of the path shapes, i.e., '60% are Cs, 20% straight C, 15% straight, 5% irregular.'" Obviously, this written feedback provided the students with a good deal of guidance; it has the same basic structure as action feedback dialogues taking place through the spoken word (student action, here of writing, followed by teacher feedback, here in writing), and like those other exchanges, it is framed by the overall project unit activity structure, with clarifications and enhancements provided by spoken verbal exchanges. In their revised report, the students carried out such an analysis with minor modifications. They used three categories instead of four, eliminating Wagner's "straight" suggestion, and reported the data by raw number and percentage, as well as in a pie chart. In their Data and Data Analysis section, they repeated their claim that "most of the recorded storms … made a C-like shape," but immediately followed it with the statement "According to our data, 52% of the storms formed this common shape." The percentages of the other shapes were also included in the text.

Elsewhere (Polman, 2000; Polman & Pea, 2001), I have described the extended sequence of communication regarding TJ and Dave's analysis of hurricane shapes as "transformative communication." As Pea (1994) used the term, transformative communication occurs for teachers and learners to the extent that both participants' understandings are changed. In this extended series of written and oral exchanges, Dave and TJ introduced the notion of the C shape without knowing how to support their claim other than by pointing to the set of 11 maps. Wagner saw that other shapes existed in some cases and was reminded of the data analysis strategy of categorization schemes and introduced it in the action negotiation dialogue in which they discussed its possibility in reference to the maps. Dave and TJ did not initially appropriate the categorization scheme, however, so Wagner reiterated it in writing. After the written feedback, it was appropriated by Dave and TJ as evidenced by its inclusion, with modification, in their report and their use of specific numbers and a graph in their next project on avalanches.

Unlike much of authentic science practice, Dave and TJ's project did not seek to explain the phenomenon they described of the C-shape. The fact that Dave and TJ's project was descriptive of patterns, rather than explanatory of why those patterns occurred, was not unusual in Wagner's class. Explanation and theorizing are important aspects of scientific discourse and practices, and numerous reform projects aim to involve students in their generation and defense (e.g., Duschl & Gitomer, 1997; Reiser et al., 2001; Sandoval et al., 1999). Wagner tended toward encouraging purely descriptive projects and research questions, such as the example of wolf pack distribution generated in the brainstorming session, and stressed use of empirical data to show patterns regardless of whether the data analysis provided an explanation or connected to a theory. Nonetheless, Wagner mentioned the idea of explanation, but it was not taken up in the hurricanes project. For instance, he mentioned that scientists "want to know why things happen" in the initial handout and asked TJ and Dave in response to their first paper draft, "Is there any similarity/significance to where the hurricanes actually turn?" This avenue could have led to east–west divisions of hurricane territory, explanations of shapes, and/or claims about the relation between land and shape. As with the overall prevalence of the C-shape, Dave indicated he had a sense that hurricanes hitting land was somehow related to shapes other than the standard C. Dave said, "some of them occasionally" hit land and drew an irregular shape in one of the two paths he traced over land. Despite not taking up the challenge of explanation in the hurricanes project, Dave and TJ did attempt to explain avalanches in their next project. They explored whether avalanches were related to amount of snowfall. As they said, "Originally we thought that maybe in a year with more snowfall there would be more avalanches, or in a year with less there wouldn't be as many." However, their data did not bear out this relation. They then wondered what role temperature played in avalanches but could not locate the needed temperature data.

Overall, Dave and TJ made significant progress in appropriating Wagner's notions of using data as evidence to prove something. As a whole, students used the terms evidence and proof frequently in their project presentations as well as their interviews after their projects, and not a single student used either of these terms in their initial interviews or during class prior to the research proposal phase of the project. When I asked Dave what he thought made for a good scientific project, he replied

> I've been like thinking about that when we've been doing it. And, I mean, you can get a topic, and just, you know, and you can just talk about it, but then I think what makes things good scientifically is probably like, just the analyzing it, and comparing, and like, you know, making graphs, comparing things with other things, making assumptions, and you know, just doing scientific, you know. Getting, you know, just like data analysis, and like using your data to *prove* a point. I mean, all that is just real science.

Besides the delight science educators would take in a student "thinking about" what makes for good science, Wagner's efforts to make data analysis move beyond just "doing steps" in a laboratory obviously bore fruit. In some laboratories, a data analysis step may just take one to the next step, but in Wagner's project, he challenged students to show their claims were supported by data.

Using Inscriptions as Compact Forms of Data

Dave and TJ's use of two-dimensional maps with hurricane paths represented by lines and a pie chart to show percentages of hurricanes that fit categories of shapes are both good examples of inscriptions used to make a point. Latour (1987) showed that inscriptions such as tables, maps, charts, graphs, and animations are an important aspect of the practice of argumentation and communication in science. Such inscriptions compactly package and, when used well, convey patterns and interpretations of the meaning of the data. Building on this insight, a growing number of educators (e.g., Forman & Ansell, 2002; Gordin, Polman, & Pea, 1994; Lehrer, Schauble, Carpenter, & Penner, 2000) have attempted to incorporate more sophisticated uses of inscriptions within inquiry-oriented science and math instruction. Although Wagner did not use the term *inscriptions,* he encouraged students to use tables, graphs, and maps in their projects, and most of the students appropriated these tools through the course of their projects.

Throughout most of his written and oral commentary about what to include in their data and data analysis, Wagner stressed tables and graphs of numeric data over other types of inscriptions. For instance, in the whole class discussion brainstorming potential projects about wolves, he said they could "make a little table that shows you the number of wolves in each pack. And make a graph that shows the number of wolves in each pack, and the average number." As the students began their data collection phase of the project, Wagner made the following statement followed by two student questioning dialogues:

Wagner: [projecting to the class] All right. First of all, you need your research question. Then you need data. You know what your question is, and then you have to answer "What data do you need to answer your question?" Once you know what the data might be, try to figure out where you can find it.
S1: You want actual data?
Wagner: Yeah. People are looking for stuff all over the place, but are not necessarily sure what they are looking for.
S1: So you want the actual data. Not just an overview
Wagner: Yeah, and preferably you should put it in table form.
Dave: A table?
RW: Not all data would go in a table. It will either be in a table or pictorial. For example, hurricane tracks could be images, but they're still data.

Through Dave's question and their project, Wagner was reminded that usable data did not only come in tables and numbers but instead sometimes came in visual images. The students' project in effect showed Wagner that such inscriptions as hurricane path maps were something worth encouraging. In addition, the possibilities for hurricane path and location analysis reminded Wagner of some of the problems he and his colleagues had encountered and addressed in conducting geological research during his master's program in the field. They used categorization schemes to describe phenomena, and they also broke spatial areas up into grids and counted occurrences of substances within each cell of the grid. In the action negotiation dialogue on analysis strategies to show a pattern such as the C shape as well as in his written comments on the students' first draft of their report, Wagner shared these inscriptional conventions with the students. Wagner routinely drew tabular arrangements and pictorial representations on students' reports; on Dave and TJ's first draft, he sketched two sets of three maps and a grid example; in their second paper draft, he sketched an alternative table arrangement and a scatter plot graph.

Through the course of their project, Dave appropriated the use of graphs and images within science inquiry. Wagner's frequent mention of tables and graphs and inclusion of maps and other images was taken up in the previous student questioning dialogue and other conversations, and students instantiated reports with such elements. With each revision of the reports and finally the presentation, Dave and TJ refined their inscriptions to focus on their relevant data and on their claims about that data. The development of the claims about shapes of hurricane paths and the pie chart that supported their assertion that "most of the hurricanes followed C-shape paths" was described in the previous section. In addition, Wagner pushed the students to realize that the patterns of hurricane paths they could describe included not just issues of shape but also location. In their Data and Data Analysis section of their first report draft, the students described their starting and ending point map as showing "that the majority of the starting points were south of Florida with their ending points arriving either right around Florida or far east into the Atlantic." Wagner's feedback included the comment that

> I think you should try to define the boundaries of the paths in terms of latitudes and longitudes. Then you can say something like "between 1985 and 1995 all the hurricanes tracked through an area bounded by __ N and __ N lat., and __ and __ W long."

The students did not just follow Wagner's suggestions as verbatim orders, however. In their final report draft, the students combined Wagner's suggestion with their own preference to talk about separate boundaries of the starting points and ending points:

> From our starting and ending point map, we found that the starting points were below 30 N and above 8 N. They were also between 45 W and 105 W. The ending points arrive in the region between 30 N and 40 N, and between 45 W and 105 W.

Perhaps recognizing that such a text was harder to understand than a map depicting the same thing, the students added a set of rectangular boundaries on a map to their project presentation to show the locations of these areas that the starting point fell in and the ending points fell in. The map with the rectangles showed that most of the ending points were north of most of the starting points, with just a small area where the starting and ending overlapped.

As with the other elements of inquiry, Dave and TJ carried this practice of using inscriptions to summarize their data and interpretations to their next science project. Dave also mentioned creating charts and graphs on the transfer task. Wagner's conversations with students, and in some cases sitting down and working in Microsoft Excel®, routinely resulted in the refinement of tables, graphs, and images to make sense of data and to convey interpretations.

REALIZATION OF THE PROJECT UNIT ACTIVITY STRUCTURE

In Figure 1, I summarized the planned project unit activity structure for Wagner's class as he distributed it at the beginning of the project cycle. It is worth looking at how this idealization played out in the specific "realization" (Bruce & Rubin, 1993) of Dave and TJ's project. Figure 3 summarizes the realization of the unit activity structure for the hurricanes project. The addition of a research report revision was a basic change in the set of milestone artifacts, but there were more interesting changes. When compared with Figure 1, the realization was clearly messier and more complex than the ideal. One would expect this finding, but the kinds of complexity are important. One of the primary ways in which the realization of this project is more complex is the fact that the portions of the project are more bidirectional and mutually informing than the ideal appears. For instance, Dave and TJ's Background Information included some data, and their research proposal was informed by the data that they had located as well as leading to more data collection. In addition, the meaning of the research question was refined over time, specifically by the clarification that the students came to some conclusions about hurricane path shapes and locations. In addition, data analysis was not really even begun at Milestone 5, and the refinement of data analysis continued through Milestone 8. Milestone 5 included some transformation of the data onto transparencies, but then in Milestone 6, claims were added about hurricane path shape but lacked evidence. In Milestone 7, those claims were supported with raw numbers of shape categories, percentages, and a pie chart. In Milestone 8, one map showing hurricane locations was refined as well.

The cyclical refinement of research questions, analysis techniques, and interpretations is an important part of the practice of science (Kolodner, Gray, & Fasse, 2003; Schwartz et al., 1999) that is reified in the practice of these high school students. In his discussion of the milestones with his students, Wagner had foreshadowed this nonlinear nature of science inquiry, saying

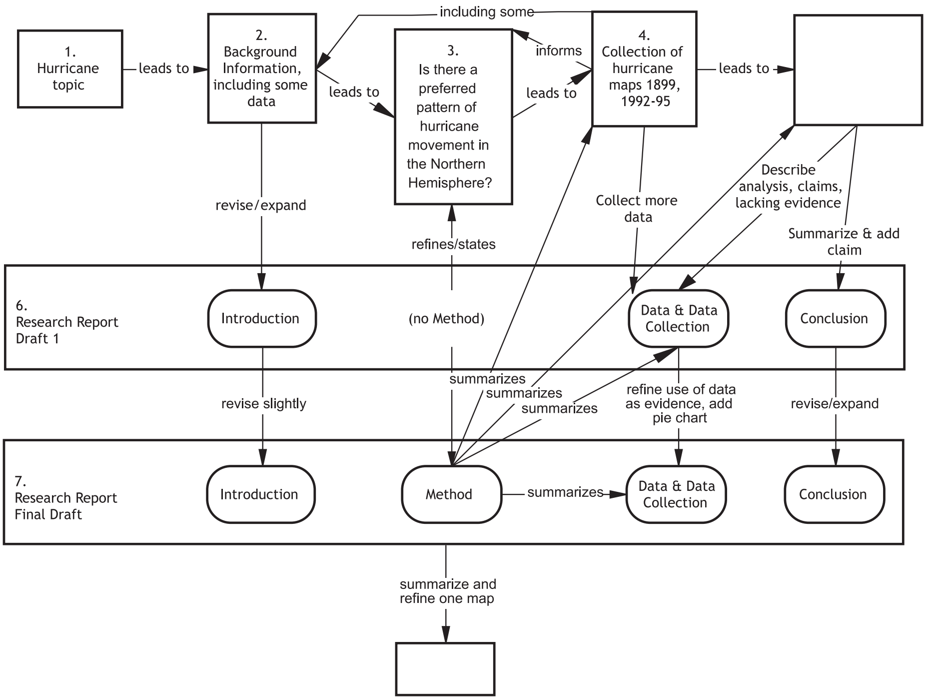

FIGURE 3 Realized project unit activity structure for hurricanes project.

> There are things that you have to do to do science, but there is no step-by-step fashion, that you're led to believe, in doing experiment after experiment from grammar school up to now, that if you just follow the right steps, you'll get the right answer.

Like the scientific method students often learned in school, Wagner knew that his project unit activity structure in the ideal could not capture all the recursiveness and improvisation of actual inquiry, so he was inclined to use it as a starting point and then guide activity from there.

In addition, this realization of the project unit activity structure provides the flexibility for the kind of dialogicality that neo-Vygotskians claim would lead to ontogenesis or the development of learners through extended periods of time (e.g., Saxe, 2002; Wertsch, 1998). The milestones provided occasions for the students in Wagner's class to instantiate in artifacts their developing understandings both of how scientific inquiry is practiced and their conceptual understandings of the content they were researching. The oral, written, and drawn artifacts created by students "took up" or appropriated ideas and terms introduced by their science teacher and were responded to and mutated by oral, written, and drawn artifacts by the teacher, which the students subsequently appropriated—or in some cases did not appropriate. The mediation of the written and drawn artifacts probably helped greatly because such artifacts are both stable and mutable within certain constraints, whereas the spoken word in conversation is fleeting and thus more easily distorted in memory (Cole, 1996; Latour, 1987; Wertsch, 1998).

FUNCTIONS OF DIALOGIC ACTIVITY STRUCTURES FOR PROJECTS

Based on my analysis of the case and discourse in Wagner's classroom, it is possible to characterize the functions of the project unit and verbal exchange activity structures within this project-based learning environment.

Like the participant structures of reciprocal teaching (Palincsar & Brown, 1984) and Herrenkohl and Guerra's (1998) adaptation of complex instruction to fourth-grade science, the project unit activity structure based on milestone artifacts is strongly tied to the goals and structure of the discipline or domain under study. In the case of reciprocal teaching, students take on roles of comprehension monitoring, summarizing, predicting, and questioning that correspond to metacognitive strategies expert readers employ. In Herrenkohl and Guerra's participant structure, students take on intellectual roles of making predictions and building a theory, summarizing results, and relating the evidence or results to the prediction and theory. These are aspects of scientific reasoning that experts employ. Similarly, the project unit activity structure Wagner developed demanded that students

1. Build each step based on the previous, so that, for instance, students had to consider the relation of what was already known and established about a scientific topic that they synthesized in one milestone and focused research questions that could relate to it for the next.
2. Consider how research questions could be examined with empirical data analyses.
3. Consider how claims could be supported with empirical data analyses.
4. Consider how inscriptions could be used to summarize data and convey findings.

Students in Wagner's class had to deal with these considerations in their daily conduct of inquiry, in their thinking process leading to the construction of artifacts demonstrating their knowledge, and in the form of those artifacts themselves. Like the participant structures for reading and fourth-grade science, this activity structure for middle and high school project science exemplifies an application of Vygotsky's (e.g., 1978) notions about the social origin of an individual's mental functioning. In all these cases, the hope is that by participating socially in these activities, students will master and appropriate (Wertsch, 1998) the tools of the domain as individuals as I have illustrated in the case of Dave and TJ.

The verbal exchange activity structures provided a structure within which the teacher could "coach" or guide student groups in their inquiry while the students maintained a high level of agency. As Duschl and Gitomer (1987) recommended, these conversational structures allowed the teacher to receive information from students about their conceptual and practice-oriented understandings and use it to assess and guide their next steps. Across the entire project cycle, the verbal exchange activity structures informed aspects of action in project-based classrooms that related to disciplinary learning such as formulating empirical questions and supporting claims with evidence. This research does not lead to simple recommendations for conducting certain numbers of exchange structures at various points in projects but instead illustrates how student questioning, action negotiation, and action feedback can provide essential guidance to learners from their more expert teacher on both expected and unexpected issues that would be difficult to obtain were teachers controlling the discourse with the more directive I–R–E structure.

Interestingly, it is precisely in the interactions of the dialogic activity structures at two different time scales that the greatest power lays. The project unit and verbal exchange activity structures mutually informed one another to enable students to move their inquiries forward as well as provide opportunities for disciplinary learning. The science project unit activity structure provided a frame that lent both impetus and meaning to the verbal exchanges. For instance, students and the teacher frequently held action negotiation dialogues when initiating or culminating a phase of the project such as data analysis. They held frequent action feedback dialogues subsequent to the completion of a phase, and they held many student questioning dialogues about procedures, assessment, and scientific practice throughout the entire process. In this way, the project unit and the verbal exchanges were mutually constitutive of the learning experience.

CONCLUSION AND IMPLICATIONS

In this article, I have demonstrated how activity structures scaffold children's performance of complex open-ended projects. For the activity setting of a project-based earth science class, I showed how activity structures at two different time scales supported students in the accomplishment of science research. On a more long-term scale, the milestone activity structure worked by taking advantage of a synergy between a small set of interim material artifacts and the portions of a later artifact the youths produced (a science research report). On a shorter time scale, the repetition of action negotiation dialogues, student questioning dialogues, and action feedback dialogues enabled a teacher to provide active guidance in the practices and norms of the discipline under study—in this case science—while demanding and enabling students to remain learners with agency rather than passive receptacles.

Based on these findings, one would expect that broad participant structures and project unit activity structures would need to be customized for different domains of learning. For instance, I have conducted after-school history inquiry using activity structures that relate to particular historical concerns such as understanding 19th-century slaves' and abolitionists' perspectives within their historical context (Polman, 2004). In this case, the activity structure for constructing "historical reenactment" Web pages with links embodies a concern with contextualization and perspective taking in history (Davis, Yeager, & Foster, 2001; Wineburg, 2001). Further research, particularly design research (Edelson, 2002) involving project unit activity structures and their impact on learning process and outcomes in different domains, would enhance our theories and practice.

On the other hand, the verbal exchange dialogic activity structures of action negotiation dialogues, student questioning dialogues, and action feedback dialogues would seem to have broad applicability to other open-ended, project-based learning environments involving the construction of artifacts. These sorts of dialogue sequences are well adapted to guiding students in carrying out actions while they are in the process of gaining expertise. Further research to refine our understanding of this phenomenon in these sorts of project-based activity settings is also warranted.

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