IV

Developing Talk That Interacts With Text in Domains of Knowledge

CHAPTER 12

Transformative Communication in Project Science Learning Discourse

Joseph L. Polman
University of Missouri

Roy D. Pea
Stanford University

TEACHING CHALLENGES AND THE CONSTRUCTIVIST LEARNING PARADOX

How can teachers help their students learn ideas and strategies that are almost completely foreign to the students' experiences? This problem is faced daily by teachers who are trying to help their students learn complex subject matter and tasks such as scientific or historical inquiry. Traditional wisdom would have the teachers simply *tell* their students what they need to know. However, constructivist theory and research, including Piagetian, information-processing, and social constructivist approaches, has done much to emphasize that telling students is not enough to ensure that they have learned something. Instead, the students must construct their own knowledge, perhaps with the teachers' help. Say a teacher is trying to help students learn how to use data from an analysis as evidence to support a claim in scientific inquiry, in a way that seems much different from anything the students have been challenged to do in the past. Popular wisdom, rooted in the work of Dewey (e.g., 1902), would have the teacher ask the students to "learn by doing" within the context of a science research project. Still, if students lack a preexisting foundation of knowledge and experience that can be easily related to the science research project, the teacher's invitation to "do a project" will fall on uncomprehending ears. How can students build this new knowledge when there is seemingly no foundation and few raw materials in their mental toolkit with which to build the desired cognitive structures?

This question is related to a problem sometimes referred to as the "learning paradox." As numerous theoreticians and researchers have pointed out (e.g., Bereiter, 1985; Fodor, 1975, 1980), the commonly held view that knowledge is actively constructed by learners encounters a paradox at a fundamental level. How learners can process information so as to construct new cognitive structures that are more complex than their already existing cognitive structures is unclear. As Fodor (1980) forcefully put it:

> There literally isn't such a thing as the notion of learning a conceptual system richer than the one that one already has; we simply have no idea of what it would be like to get from a conceptually impoverished to a conceptually richer system by anything like a process of learning. (p. 149, cited in Bereiter, 1985)

In this chapter, we argue that a solution to the learning paradox as well as teachers' everyday dilemmas lies in a neo-Vygotskian theory of distributed intelligence and transformative communication. After laying out the theoretical background, we illustrate the use of a specific discourse strategy for transformative communication that has proven particularly useful in teaching-learning situations such as project-based science.

DISTRIBUTED INTELLIGENCE AND THE LEARNING PARADOX

In previous works, Pea (1993b, 2002) has argued that intelligence is more realistically conceived as distributed among persons and the symbolic and physical environment rather than within individual, isolated minds. In addition, intelligence is more aptly viewed as manifest in the dynamics of activity, rather than as static. The distribution of intelligence among persons is often evident in collaborative activity (e.g., Barron, 2003; Roschelle, 1992) and dialogue in parent-child dyads (e.g., Rogoff, 1990)—in many such instances no individual can be said to be the one who has solved a problem or accomplished an activity. One of the most evident examples of this co-constructive activity lies in early language development—the transitional time following the single-word utterance period, and before the regular use of syntactic, multiword utterances, is marked by the collaborative development of full sentences, over speaker turns and across speakers (Ochs, Schieffelin, & Platt, 1979). Consider an example described by Wertsch (1991): A child has lost a toy, and she approaches her father for help. The father does not know where the toy is but asks the child a series of questions that help her structure her search. Did she have it in her room? No. In the yard? No. In the car? That could be. They check and find the toy in the car. It is the child-parent *system* that solved the problem, with unique contributions from both persons that the other did not supply. Numerous researchers and theorists following in the footsteps of Russian sociocultural research (e.g., Leont'ev, 1981; Vygotsky, 1978) have been refining the vision of intelligent action carried out between persons, in what Wertsch (1991) terms the *intermental* realm.

As Pea has recounted in more detail elsewhere (1993b), he was struck by the fact that although many were recognizing the distribution of intelligence across persons, the contribution of designed objects such as physical tools, computer programs, or inscriptional systems such as x-y coordinate graphing to intelligent action was often neglected. Vygotsky (1978) had emphasized the importance of cultural tools in mediating human action, but he had focused on language as a tool. Ironically, given the concreteness of the "tool" metaphor, concrete physical tools and nonverbal but semantically rich representational systems had often been neglected in analyses of distributed cognitive activity. But the integral use of artifacts such as pencils and lists in everyday cognitive achievements highlights the ubiquity of tools in our surroundings, which have certain sorts of intelligence "built in." Some of our work has focused on how educational designers can build in more effective affordances for cognitive tools such as software designed to support science inquiry (e.g., Edelson, Gordin, & Pea, 1999; Gordin, Polman, & Pea, 1994; Pea, 1993a, 1998) in the geosciences.

In this chapter, and other recent work, we are more directly concerned with the ways in which intelligence is distributed in social arrangements and activity structures that support human learning through "guided participation" (Polman, 2000, in press; Polman & Pea, 2001; Rogoff, 1990). Examples of such arrangements include Palincsar and Brown's (1984) influential model of "reciprocal teaching," in which the teacher places students in roles that divide important aspects of the reading task, supports the accomplishment of those roles, and through repeated activity involving role shifts for students brings the group as a whole to more expert performance.

Strategies such as reciprocal teaching are based on Vygotsky's (1978) "general genetic law of cultural development." Vygotsky held that learners accomplish activities with the help of more expert others in a social setting—on the intermental (Wertsch, 1991) plane between minds—that the learners could not achieve on their own. This sort of intermental action is for the individual learner what Courtney Cazden (1981) aptly calls "performance before competence." After such performance, learners can advance their own understanding, on what Wertsch terms the *intramental* plane (i.e., within an individual's mind). The student-and-teacher-acting-together-in-the-world thus provides a structure, which the student can then internalize so that the student can later act in a similar fashion without the teacher's help (Cole, 1996). Related considerations apply to the conditions under which an individual may elect to use external representations or tools in the environment to serve as scaffolds of their own activity, because of the stressful demands of the task situation—"internalization" is thus not a trait that an individual develops for a task but a state of the situation (Pea, 2004; also see Glick, 1983), as when an adult uses "egocentric speech" to help plan a complex activity in a noisy situation.

This would seem to provide a solution to the learning paradox: the building blocks for new conceptual structures are not just an individual's concepts in the head but also the sociocultural world and actions in it that can be internalized. As Bereiter (1985) has pointed out, however, there is a catch in the use of the term *internalized*, which Vygotsky's research group also recognized. If the more complex cognitive structures end up being completely "in the head," then their building blocks must also be located there. To some degree, this problem is mitigated by the idea that the memories of action sequences carried out with the support of others could serve as the building blocks themselves, provided the actions are designed in such a way as to scaffold for future "fading" of support (for an example with reading strategies, see Cole, 1996, pp. 272–280). Researchers rooted in the tradition of computational cognitive modeling of individual minds have been exploring this sort of learning for some time, under the rubric of case-based reasoning (e.g., Kolodner, Gray, & Fasse, 2003; Schank, 1990); they have developed information-processing paradigms whereby the memories of event sequences can be stored, retrieved, and adapted in reasoning about possible future actions.

Regardless of the adequacy of such approaches, we would join others in emphasizing that not all forms of distributed intelligence can reasonably be described as eventually or ideally "internalized" (e.g., Hutchins, 1993, 1995; Pea, 1993b, 2004; Wertsch, 1997). To take Hutchins's oft-cited example, the idea that the navigation of a large naval vessel is or should be meaningfully located in one individual's head verges on nonsensical: The carrying out of navigation is always and always should be embedded within a distributed social and material-technical system. In the social realm, many persons playing complementary roles are necessary, and in the material realm, a great deal of specialized equipment with embedded intelligence of various sorts is necessary. Exploitation in the real-time achievement of intelligent activity is also required.

Due to consideration of cases such as navigation, and the ongoing importance of context and tools for much intelligent action, many researchers have come to prefer terms such as *appropriation* (Brown et al., 1993; Pea, 1992; Rogoff, 1990) and/or *mastery* (Wertsch, 1998) rather than *internalization*. Unlike internalization, the terms *appropriation* and *mastery* do not imply that residuals "in the head" are unsupported by tools in the world. Some sort of mental representations are appropriated by individuals intramentally and can be applied across multiple contexts, but the mental representations do not do the work of cognition alone. Because much of the complexity of cognitive achievements *always* remains in the cultural and material world, the learning paradox is not necessarily a problem. There are continually dialectical processes in which the "internal uses" of cognitive structure are complemented by the affordances of external tools, representations and features of the physical as well as social environments in which the learner operates. The tools that an individual needs to carry out actions may not be available in all settings, but part of what humans do is create or arrange their environments so that not all the work to be done requires mental gymnastics (Pea, 1993b). Further, it is important to note that the individual mental representation involved in mastery of a tool does *not* require a full description of a tool's complexity. In other words, the understanding of how tools work is not necessary for their mastery. For example, we do not have to understand how our computers work at the electronics level or even the programming level to use our word processors in an expert way. Recalling Cazden's (1981) phrase "performance before competence," we are emphasizing that "competence" does not always imply complete understanding of all aspects of the performance; rather, the person's contribution to intelligent action must "dovetail" (Clark, 1997) with the tool's affordances. Dovetailing effectively with tools in the world does not require that we have complete copies of tools and how they work in our heads (Clark, 1997). We may have to understand a good deal of how the computer and software works to *invent* the word processor from scratch, but as James Burkes's *Connections* series remind us, even inventions often involve the combination of existing ideas and devices in new ways, with or without an understanding of the parts' origins and operation. The re-usability of intelligent tools designed for certain purposes is the great insight of object-oriented programming: Code that performs certain operations does not have to constantly be reinvented but instead can be invoked from within multiple contexts.

TRANSFORMATIVE COMMUNICATION IN GUIDED PARTICIPATION

Although the learning paradox may not be a philosophical problem given this neo-Vygotskian viewpoint, how to support learners so that they can appropriate some valued aspects of activity is a constant dilemma for teachers. In Vygotsky's (1978) terminology, the *zone of proximal development* (ZPD) describes the limit of actions that learners can meaningfully participate in intermentally, and subsequently appropriate intramentally. Beyond the ZPD, learners cannot relate actions to their current understandings.

How teachers and students can accomplish learning and activity in the ZPD is not at all straightforward. To be most effective, teachers must diagnose where students are developmentally and figure out, in each case, what it would look like for the students to perform meaningfully, if not yet fully competently. For teachers, like experts in a domain, it may be quite difficult to avoid inadvertently acting outside a novice's ZPD. In our work within the CoVis project (Pea, 1993a), we were faced with these issues in a realm where students appeared to be facing somewhat of a "bootstrapping" dilemma: They had few experiences that helped them to know how to carry out certain aspects of science inquiry, much less use the Internet and scientific visualization tools in the context of that higher-order activity (Polman, 1996). Thus, if the teacher just gives them a clearly circumscribed path, as is done in many traditional labs, the meaning of the actions students carry out will not necessarily relate to the teacher's goal of students learning about experimental design (because the students are not required to *participate* in the design). This problem is also too often manifest in various forms of student-scientist partnerships in education (Cohen, 1997). In studies such as the multinational precollege GLOBE Project (Global Learning through Observations to Benefit the Environment), students collect data around the world. They do so according to protocols that are designed by scientists to ensure data quality and reliability, and without care, in designs such as these, learners may be relegated to the role of "databots," collecting data without an understanding of the designs that render the data meaningful (Pea et al., 1997). Teachers cannot just give the students the steps to follow by rote, nor can they leave the students unguided to recapitulate the development of all science knowledge. What is needed is some kind of interactive process of guided participation, which allows the student to be an active inquirer and the teacher to be an active guide. "Transformative communication" is one such process for guiding participation (Pea, 1994); we came to see that it provides some explanation of why certain incidents prove productive for teaching and learning in a project-based science classroom.

The view of communication as *transformative* can be contrasted with common views of communication as *ritual* and as *transmission* (Pea, 1994). The view of communication as ritual tends to encourage active participation by all parties, but in activities with already shared meanings. The ritual nature of much cultural activity helps to explain how it is successfully carried out: for instance, telephone greetings rely on a highly specific series of key words, pauses, and intonations to get a great deal of information across quickly (Schegloff, 1979). Despite the obvious importance of ritual communication in cultural activity, it does not involve the sort of generativity at fostering new development that is needed for education.

The dominant view of communication in learning settings as *transmission* of knowledge from the teacher to the student (Cohen, 1988; Pea, 1994; Polman, 2000) is associated with entirely teacher-directed pedagogy such as lectures (Rogoff, 1994). In lecture-based classrooms, the teacher is an active presenter of knowledge and the students are passive receivers of knowledge. In part because of the recognition already discussed that knowledge is actively constructed (e.g., Bransford, Brown, & Cocking, 1999), educational reform efforts such as project-based learning are often designed in hopes of changing the students' passivity. When implemented as *unguided discovery,* however, project-based learning demands that students become active in the acquisition of knowledge, but it leaves *teachers* passive. Rather than either of these extremes, educational researchers have come to recommend the model of *"community of learners,"* in which "learning occurs as people participate in shared endeavors with others, with all playing active but asymmetrical roles" (Rogoff, 1994, p. 209; see also Brown & Campione, 1994). Teachers interested in supporting inquiry learning, rather than just "letting their students go" to see if learning will occur, would thus do well to try to create a "community of learners" atmosphere in their classes. This implies that they must play a unique role of structuring and guiding student activities without taking away the students' active role. Some researchers refer to this middle ground as "guided discovery" or "guided learning," but note that the role of guide is difficult to master. Ann Brown (1992) notes,

> Guided learning is easier to talk about than do. It takes clinical judgment to know when to intervene. Successful teachers must engage continually in on-line diagnosis of student understanding. They must be sensitive to overlapping zones of proximal development, where students are ripe for new learning. Guided discovery places a great deal of responsibility in the hands of teachers, who must model, foster, and guide the "discovery" process into forms of disciplined inquiry that would not be reached without expert guidance. (p. 169)

As Brown points out, the complexity of structuring and guiding students in project work is increased because different students in a class need different levels and kinds of support; because their existing knowledge bases are different, the individuals in a class end up interpreting whatever support they get, even if it is a statement by a teacher to the whole class, differently as well. Matching the kind and level of support students need with what a teacher provides them is a difficult balance to maintain, though. Consequently, as one teacher put it, a teacher trying to support students can "feel sort of like a tree swaying between two extremes of providing students with structure and allowing them to do it all themselves." One way to conceptualize teachers' new role in such classrooms is by *scaffolding* student work (Collins, Brown, & Newman, 1989). Scaffolding can occur either by modeling, by structuring activity, or by coaching—supporting and guiding students' work along the way. In this chapter, we are most concerned with the use of one powerful form of coaching, transformative communication, in a project-based science class. So what is transformative communication? Pea (1994) has described it as follows:

> The initiate in new ways of thinking and knowing in education and learning practices is transformed by the process of communication with the cultural messages of others, but so, too, is the other (whether teacher or peer) in what is learned about the unique

> voice and understanding of the initiate. Each participant potentially provides creative resources for transforming existing practice. (p. 288)

Transformative communication is achieved through mutual appropriation (Newman, Griffin, & Cole, 1984; Pea, 1993b) by participants in social interaction to create meanings that neither participant alone brought to the interaction. In some project-based science classrooms—ones designed to support students in carrying out their own original research—it involves transforming students' actions into more successful "moves" in the "language game" of science (Wittgenstein, 1967). Put another way, it allows students to participate in a new way in "talking science" (Lemke, 1990; Pea, 1992).

GETTING TO SPECIFICS: METHODS, DATA SOURCES, AND FRAMEWORKS

All this discussion will only be meaningful insofar as it can be related to specific learning environments and conversations. For the balance of this chapter, we discuss episodes involving transformative communication in one classroom.

The episodes related in this chapter are part of a larger interpretive case study (Polman, 2000) conducted from 1994 through 1996 in Rory Wagner's[1] class, one of many participating in the CoVis Project. One of the central features of the class was that students conduct Earth Science projects *of their own design.* What this meant in practice is 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 in both written and oral formats.

Polman was a participant observer in Wagner's classroom for 3 years—1½ years acting as a technical assistant and 1½ years conducting the formal study (1994–1995 through winter 1995–1996). Data were collected in field notes and videotapes of classroom observation at each project phase, artifacts created by the teacher and students, and formal and informal interviews with the teacher and selected students. Formal interviews were recorded with audiotape and transcribed, whereas informal interviews were recorded with handwritten notes. For this chapter, we use to illustrate ways transformative communication was used in specific episodes to scaffold students' accomplishment of science inquiry.

Our interest in these episodes began with a vague recognition that they seemed to involve some sort of "ah ha" quality among participants and played a key role in the subsequent success of the projects of which they were a part. We thought that a better understanding of the episodes might enable researchers and teachers involved in our project to foster more widespread success, for the challenges of project-based science learning are many. We came to recognize that part of the power of the episodes was due to the fact that they involved mutual appropriation and transformative communication. We surmised that an adequate description of what was unique about them could provide elements of a prescription for future effective action. Table 12.1 provides our general description of the episodes in the form of a dialogue sequence that transformative communication followed.

We do not intend to imply that all communication that results in learning is transformative in the manner described here. Nor do we mean to imply that all communication that could reasonably be termed transformative follows this sequence in strict stepwise order; the sequence is intended to describe the general

TABLE 12.1
Dialogue Sequence for Transformative Communication

(1)	Students make a move in the research process with certain intentions, guided as well as limited by their current knowledge.
(2)	The teacher does not expect the students' move, given a sense of their competencies, but understands how the move, if pursued, can have additional implications in the research process that the students may not have intended.
(3)	The teacher reinterprets the students' move, and together students and teacher reach mutual insights about the students' research project through questions, suggestions, and/or reference to artifacts.
(4)	The meaning of the original action is transformed, and learning takes place in the students' zone of proximal development, as the teacher's interpretation and reappraisal (i.e., appropriation) of the students' move is taken up by the student.

trajectory of some key dialogues, which inevitably involve a great deal of interactive give-and-take that we are not going to examine at the level of detail afforded by, for instance, conversation analysis (as in Polman, in press). What we hope to accomplish with analyzing this dialogue sequence is twofold: (1) to describe important features of dialogue that have proved productive in transformative teaching-learning episodes, and (2) to provide a discourse strategy that teachers may productively use as a cultural tool in future episodes with their students. In summarizing these cases, we focus on how student groups conducting projects arrived at an incident of transformative communication, their interaction with the teacher going through the steps of the dialogue sequence, and the subsequent impact of the transformative communication event on the progress of their project.

PLESIOSAURS: TRANSFORMING A QUEST FOR "THE FACTS" INTO A RESEARCH QUESTION

As detailed elsewhere (Polman, 2000, in press), Wagner guided his students through open-ended projects through a project unit activity structure (Doyle, 1979; Lemke, 1990; Mehan, 1978) consisting of several parts, each leading to the next, with "milestone" deliverable artifacts due from the students at many of them. The complete series of milestones was (1) select group and topic, (2) write up background information, (3) provide research question/proposal, (4) collect data, (5) analyze data, (6) complete research report modeled on the scientific research article genre, (7) revise research report, and (8) present to the class. Somewhat akin to inscriptions made by professional scientists (Latour, 1988; Gordin, Polman, & Pea, 1994), the written milestone artifacts are "shared, critiquable externalizations of student knowledge" (Blumenfeld et al., 1991; Guzdial, 1995) that become useful as occasions for feedback and transformative communication.

Three 11th-grade young women named Beth, Laura, and Cindy teamed up for their first project in Wagner's class. Beth emerged as their leader, with Laura making frequent contributions and Cindy mostly remaining quiet in the background. Cindy and Laura decided one day when Beth was not present that their project topic should be an extinct sea creature called a "plesiosaur." Part of the creature's appeal was its long neck, somewhat like that of a brontosaurus, which made it look in artists' renderings like the fabled Loch Ness monster. Beth, Laura, and Cindy initially had a great deal of trouble locating any specific details on the plesiosaur for the "background information" phase, but with Wagner's assistance they located World Wide Web resources related to the creature. They used the information from the Web and library books to write up their background information report. During the following week, the Plesiosaur group had to complete their focused research proposal. After a whole-class, teacher-led discussion on research questions, students began working in their groups generating potential questions about their topics. The next day, Beth and Cindy approached Wagner to announce they had a research question: "Are accumulations of plesiosaurs associated with areas of high marine productivity?" Wagner was pleased that they followed his advice on choosing a question examinable with empirical data, but he feared the spotty plesiosaur fossil record would prevent the students from coming to valid conclusions about locations in which they thrived; in essence, some locations where plesiosaurs dwelled might have been conducive to fossil formation and discovery, and others not, leading to spurious trends. To avoid these pitfalls, Wagner asked them to reconsider what attracted them to plesiosaurs as a topic in the first place. In response, Cindy mentioned their long necks, and Beth how they swam with large flippers. That reminded Wagner of a comment Beth had made while looking at library books 2 weeks earlier. She had announced, "This [book] says they flew through the water like sea turtles, and sea turtles swim very quickly … This [book] says they didn't swim very quickly." Wagner had not followed up on the comment at the time, perhaps because he was interrupted by a question from another student. The group had not mentioned swimming speed in their background information milestone report, but the teacher recalled it. Referring to these books, he asked, "Didn't you read a debate about whether [plesiosaurs] were fast or slow swimmers?" Beth confirmed, "Some of them said they were fast and some said slow."

In this exchange, it is notable that Wagner interpreted and recalled the conflicting accounts of plesiosaur swimming speed as a scientific debate, which he understood in terms of the scientific community of scholars attempting to reach consensus. The student, on the other hand, had simply noted that the accounts related different ideas but did not understand those ideas within the frame of "scientific debate." Based on his assumption that there was a debate about swimming motion, Wagner suggested they could do an "analysis of swimming motion … like how fast they go. You would need to know how animals move and how they swim." Thus, Wagner "revoiced" (O'Connor & Michaels, 1996) the information Beth had originally stated, with a reconceptualization (Cazden, 2001) to include the notion of scientific debate. Beth and the other members of her group liked the idea and decided to run with it. As Beth said, it reminded her "of the reanalysis of dinosaurs that they did and whether they were slow or fast—Jurassic Park was more accurate than the old picture of lumbering dinosaurs." With this reference to a popular culture notion that helped her understand scientific debates about the speed of extinct creatures, Beth began to better understand the process of science inquiry.

Following this discussion, during which they decided to focus on the swimming motion of plesiosaurs, the group members reviewed the relevant sections in the library books they had gathered, and Beth returned a few days later saying incredulously, "Mr. Wagner! Do you know whether the plesiosaur moved by rowing its flippers or flapping them like wings?" One of her library books reported that Plesiosaurs swam with a rowing motion, and another book mentioned that they swam by underwater flight, flapping their flippers like wings straight up and down in the water. Again, neither book mentioned a controversy. As Beth reported later, she "thought he was like all-knowing." She appeared to be looking for her teacher to provide *the answer,* the kind needed for what he called "traditional library research." Wagner was determined to have her do more extensive inquiry, however. Beth, by her own admission, "had never done a project where there [wasn't] really an answer, or someone who's already found the answer." Wagner showed Beth that her question about the swimming method could be more than a quest for the accepted fact; it could be *their research question*—*they* could assemble evidence to support their own claim of how plesiosaurs swam.

This interaction enabled Wagner to support Beth in accomplishing an activity with which she was unfamiliar, by means of the sort of "transformative communication" described earlier. We can see a concrete enactment of the 4-stage dialogue sequence shown in Table 12.1: (1) Beth approached her teacher looking for *the answer* to two fact-based questions that she expected her "all-knowing" teacher to provide: Did plesiosaurs swim fast or slow, and did they swim by "underwater flight" or a rowing motion? If she could get the answers, she would include them in her report on plesiosaurs, which she may have been seeing still as a library research project like she had done in other classes, with established facts about a topic synthesized and described. (2) Wagner did not know the fact Beth was looking for, nor was he sure there was a debate about plesiosaur swimming motion, but he did know that part of the game of science involves marshaling evidence to support one of several competing claims such as the ones in the books Beth had found. (3) The teacher reconceptualized Beth's move, admitting he did not know the answer but pointing out that an interesting project could use this as a research question. They talked about how she and the other group members could contribute new evidence to a scientific debate rather than just report others' findings. (4) Beth's fact question has been transformed into a research question, as evidenced in her subsequent practice. The student group framed their data collection and analysis in terms of this debate and marshaled the evidence they could to support the theory of a slow rowing motion.

UFO SIGHTINGS: TRANSFORMING A CITATION INTO AN OPPORTUNITY FOR CONFIRMING RESEARCH

Researchers on tutoring and project-based learning have pointed out that motivational benefits can be reaped when students are given *control* over decisions about what they do—as Wagner gave Beth and her project partners—and when they are given the opportunity to work on problems and projects that *interest* them (Blumenfeld et al., 1991; Lepper, Woolverton, Mumme, & Gurtner, 1993). Bruce, Sylvia, and Cheryl's project shows how a project built on students' interests that might seem dubious at first from a scientific standpoint can be transformed into tractable empirical research. Through transformative communication, their project went from being a project about "whether UFOs are alien space ships" to a project about confirming or falsifying natural explanations of UFO sightings.

Along with the other groups, the UFO Sightings group began their project by collecting and synthesizing background research on the topic, before deciding on a specific research question. In their interim report of background research, they mentioned the so-called Condon report (Condon & Gillmor, 1968), an official study put out by the U.S. government, in which UFO sightings were explained by meteor showers, rocket launches, and other known phenomena. Two days after he got the milestone background information reports from students, Wagner mentioned to Polman before class that Cheryl, Bruce, and Sylvia might need extra support on their project given the problematic nature of the UFO topic in the previous classes. He was pleased with the potential in the group's description of the Condon report, as the government's analysis took an empirical approach based on supportable or refutable claims about alternate explanations for UFO sightings—essentially taking a scientific approach to a problem usually approached through mere hearsay. So during class that day, Wagner initiated a discussion with the UFO Sightings group about potential research questions. The interaction with the UFO Sightings group proved a pivotal incident of transformative communication resulting in the formulation of a specific research question.

Shortly after completing attendance and answering some procedural questions from various students about the research proposal assignment, Wagner sat down with Cheryl, Bruce and Sylvia. The following interaction took place:

Rory: OK, what do you want to do?

Bruce: We want to show UFOs are alien space ships.

Rory: [doubtfully] Any ideas on how?

Bruce: I don't think there's any way to prove it unless they saw the alien in there and they waved at them. That's the only evidence there is.

Rory: Right. That's the problem.

Cheryl: I don't see why we can't write a report on it if people have written whole books on it. [Cheryl interpreted the project at this point as essentially the same as an extensive report for an English class. As time went on, she began to grasp the importance of using empirical data to support a claim.]

Rory: [does not directly address Cheryl's confusion at this time] You know, Joe [Polman] and I were talking about the analysis Condon did that you wrote about in your background information [report]. It was interesting because Condon claimed to have explained the sightings with known phenomena. [For your project] you could verify what somebody like Condon has done. That's another thing people do in science …

He described the example of the cold fusion debate a few years ago, pointing to how it could be applied in their project:

> These guys said they had created cold fusion in the lab. But when other people tried it, they couldn't duplicate what they said ... In science, once someone says they've proved something, others check it … The idea [here] is to verify the government's explanations. Say they said it was a meteor shower. You could look at the date,

> where the meteor shower was, and when and where people saw the UFO. Does it match the same spot? If the sighting was here [points one direction] and the meteor shower there [points another direction], the government's explanation could be wrong.

The students decided to run with the idea. In this example, the students originally presented the Condon report as relevant to the history of the UFO debate and thus something to be cited in a review of literature but otherwise not used. Through their interaction, the teacher and students created a new meaning for the citation: the seeds of a study intended to provide independent confirmation or falsification. Thus, this sequence of interactions, starting with the submission of the report by the students and continuing with the discussion in class, can be seen as another instance of transformative communication. The students referred to some research in their background information report, intending it as an example of what is known and has been reported about their subject. Based on his greater understanding of the scientific process of verification, Wagner showed the students they could use the study as the seeds for the next phase of the activity structure: a research proposal to independently confirm or falsify the previous research.

After this interaction, the group's research formulation proved fruitful. For their final research report, the group chose four UFO sightings from the 1960s, described in the Condon report, and tried to independently confirm or falsify Condon and Gillmor's explanations. Their independent confirmation was based on printed data sources found in library searches, such as NASA launch records (Stanford, 1990) that confirmed a scheduled re-entry of satellite Agena into the Earth's atmosphere occurred at the time an airplane crew reported a UFO over Mexico and could have been seen in that location.

Rory Wagner has found the "beginning of the project and the end of the project" to be the most difficult for students. Specifically, the early phase requires that students formulate a research question and proposal, and the later phase requires that they use data analysis to reach an empirically supported conclusion. The UFO Sightings project and the Plesiosaur project (described earlier) provide examples of transformative communication in the form of "action negotiation dialogues" (Polman, in press) around the formulation of research questions. The Hurricanes and the Moons projects provide examples of transformative communication at the data analysis phase.

HURRICANES: TRANSFORMING AN INTUITION INTO A CODING SCHEME

Dave and TJ became interested in hurricanes because of the destruction they cause. Through conversations with Wagner and a scientist "telementor" (O'Neill & Polman, 2004; O'Neill & Scardamalia, 2000) Wagner put them in contact with by e-mail, the students settled on the research question "Is there a preferred pattern of hurricane movement in the Northern Hemisphere?" Over the 2-week data collection period, TJ and Dave worked diligently to gather image data showing hurricane paths off a Web site they found linked from a page their telementor had directed them to. They began their data analysis by combining the hurricane paths onto one image, which gave them an impression of the shapes those paths could take. In an interview outside of class, Dave noted that many of the hurricanes made "a little semicircle" on the southeast edge of the United States.

However, figuring out how to turn this general impression into an analysis of data supporting their conclusions proved difficult for Dave and TJ, as it did for most of their peers in Wagner's class. They turned in an initial stab at an analysis of 4 seemingly random years and got some advice from their teacher about choosing a larger sample of continuous years. With a day to go before their research report was due, Dave and TJ had a long conversation with Wagner trying to solidify data analysis techniques. Their teacher asked them what the general pattern of hurricanes was, and TJ showed him the semicircle or "C" shape Dave had described previously. Wagner made a few suggestions for ways to systematically describe many hurricane shapes, while they continued to look over the composite image of hurricane paths. Then Wagner noticed that *not* all the hurricanes followed the C-shaped path Dave and TJ had described. Some were straighter than the standard C, and others appeared erratic. He then suggested they could devise a categorization scheme for the shapes of paths. They could go back to each year and put a categorical label on each hurricane path shape, count up the frequencies of each shape, and calculate the percentages.

The conversation about data analysis was productive from Wagner's standpoint and nearly constituted a complete sequence of transformative communication. But because Dave and TJ did not effectively take up the jointly developed idea about categories of path shapes in the day remaining for the preparation of their written project report, it was not complete.

In his extensive commentaries written on Dave and TJ's report, Wagner tried to be encouraging and concretely helpful to move them forward. He wrote that they had "made statements in this analysis section *without* referring to the data once. You *can't* do that." He pointed out specific examples. TJ and Dave had written, "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." He pushed them to "show/prove this [was] true" by showing "how many (and then, what %) of the storms had this 'C-shape' path." He pointed out how they could classify each storm in the time period as having one of a set of path shapes, such as the C-shape they mentioned.

For their revised report, the boys took up many of their teacher's suggestions, thus completing the transformative communication sequence. They categorized each storm as having one of three path shapes and gave the number of storms within each category from among the 83 storms over the period. They also produced a pie chart showing that 51% of the storms followed the C-shape, 22% a "straight-C," and 27% "irregular." The Hurricane group's revised report was a significant improvement over their first draft, with conclusions supported specifically by data analysis.

As with the group who did the project on plesiosaurs, Dave and TJ needed two tries at the third and fourth step in the transformative communication sequence, negotiating the meaning of the teacher's transformation of their idea and putting it into practice, before they could effectively appropriate the idea. In Dave and TJ's case, the second attempts at Step 3 took place in the form of an "action feedback dialogue" (Polman, in press) on their previously written-up analysis, and in Step 4 was implemented in their revised report. In addition, the transformative communication took place through a combination of written and oral verbal exchanges. In addition to the repetition in the second try and Wagner's greater specificity, the stability of Wagner's written comments as compared to his oral suggestions may have been necessary for the students to glean his intended meaning given their lack of expertise at these scientific practices.

MOONS: TRANSFORMING AN UNSUPPORTED CLAIM INTO A GRAPH OF TWO VARIABLES

For their project, Rich and Steve compared and contrasted moons in our solar system. They gathered data on various characteristics of moons, such as density, size, mass, and orbital period, and meticulously organized the data in tables and graphs—a separate graph for each variable. In numerous conversations and comments on interim milestones, Wagner pushed them to think about questions their data could illuminate, such as why the moons were different from one another or what the connections were between variables. But the students had difficulty in finding patterns.

The crucial exchange began when Rory received Rich and Steve's final research report. The students had included only graphs of single variables and then listed each graph's interpretation separately. For instance, they included a line graph showing each of the moon's orbital time period and a bar graph of each moon's density. In the text, the students wrote, "The graph [of orbital period] shows that Earth's moon has the longest orbital period, 27.32 days, while Miranda has the shortest orbital period, 1.4 days." Similar graphs in different styles were included for mass, surface temperature, and distance from planet. In the Data Analysis section of the paper, Steve and Rich did not describe any relationships between variables, except in the statement that "Titan has a short orbital period in relation to its mass"—a statement they did not choose to elaborate. But at the very end of the paper, buried in the Conclusion, they wrote something more like a testable claim: "We have come [to] the conclusion that both Titan and Earth's moon [have] a much greater mass and density than Miranda, and that this could be why both Titan and Earth's moon have longer orbiting time periods." Wagner seized this claim about how mass and density could be related to the orbital period of the moons and showed Rich and Steve how they could directly test it by graphing, for instance, density on the y-axis and time period on the x-axis.

Once again, Wagner perceived that the students' work could be transformed to a more successful move in the game of science than they themselves were originally aware. Like the group who did the Hurricanes project, Rich and Steve had developed a sense that a relationship existed in the data—that is why they put the comment in the conclusion—but they did not know how to present their data to back up a claim. In both cases, a clear analysis technique may be difficult to find even after a general impression has been reached by working with the data. Wagner's greater experience enabled him to see that a graph of one variable against the other would enable the students to directly check their claim that the two variables covaried. When graphed, it appeared that in the students' data, a relationship between density and orbital period, but not between mass and time period, was supported. Using similar methods, Wagner suggested that the students could create combination graphs for all the possible pairs of variables from their separate graphs. In this way, another apparent linear relationship was revealed—between the mass of a moon and its distance from the planet.

When Steve and Rich got the final version of the paper back, they were excited, because, as Steve put it, they "finally saw, you know, what [we] were trying to find, with the patterns." Although there was no provision for revising their paper again, the students got a chance to use the insight in their presentation to the class the following week. Steve and Rich created graphs of their own using Wagner's sketches as a model. In their presentation, they used the line graphs of two variables to support their claims, such as the one that "if a moon has a greater mass, that might affect its distance from the planet that it comes from." With statements about one factor "contributing to" or being "affected by" another, Rich and Steve had finally moved into the realm of making empirically warranted causal arguments, albeit tentative and somewhat awkwardly stated ones. As in the scientific community, they were making their claims with the aid of particular types of inscriptions—in this case, somewhat crude graphs. The graphs made their claim more compelling and understandable (Gordin et al., 1994; Latour, 1988). Steve and Rich had a great deal to learn about analyzing data, but transformative communication helped them to begin making progress.

MUTUAL INSIGHTS THROUGH CONVERSATION WITH ONE ANOTHER AND THE SITUATION

For effective teaching and learning, it is not enough for teachers to simply tell students what to do. Wagner wanted to ensure that students participated in research design and the selection of analysis techniques so that they could learn about research design and analysis strategies. This contrasts to traditional "cookbook" labs, which take such decisions out of the hands of students and consequently preclude opportunities for deeper learning likely to lead to autonomous action in the future. But involving students can be time consuming and difficult. The difficulty and pitfalls of student participation in the *whole* process of research has been recognized by a number of student-scientist collaborative efforts, but even though it is often messy from scientists' perspective to have students involved in the whole process, it is educationally significant (Pea et al., 1997). Transformative communication can prove useful in maintaining this balance between student ownership and the teacher finding ways to guide students in potentially promising directions, as *both* parties make crucial contributions. As Rory described it,

> Sometimes [students] come up with things that are really creative that I would have never thought about, which then leads me to think of other things that might be do-able. And sometimes—[and] this gets in to the negotiating thing—sometimes they get real close to something, or have a neat idea, but it's not do-able, so then, how do you turn that into something that is do-able? Sometimes they do it, [and] sometimes I can do it.

And in some cases like those detailed earlier, the students and teacher can truly do it together. In the interactions described, the teacher helped the students transform the moves they made in the research process into more sophisticated moves that neither he nor the students would have originally predicted, thus leading to *mutual insights*. The interactions can take place over an extended period of time, in real-time or written discussions, but the important thing is that *both* teacher and student participation contributes. To borrow a phrase from Donald Schön (1982), the process of transformative communication enables both Rory and his students to "engage in a conversation with the situation which they are shaping" (p. 103). In this case, it also allows them to engage in a conversation with each other. Whereas Schön was talking about reflective practitioners of design, such as architects, working alone, the process is remarkably analogous in these social interactions between teacher and student. Like architects who find "new and unexpected meanings" in drawings they create, Wagner and his students sometimes found new and unexpected meanings in the changes they produced *in one another's interpretations* and *the situation*. As Wagner stressed to his students, they *did* know important and useful things about their topic and data as they conducted their inquiry, but he often needed to help them conceptualize how what they knew could be used to accomplish scientific inquiry.

In these cases, the "project unit activity structure," with its set of interim milestones that Wagner designed for conducting projects and "verbal exchange activity structures" such as action negotiation dialogues and action feedback dialogues (Polman, 2000, in press), helped him to support students through transformative communication. The project unit activity structure set up the students' desire to formulate a researchable question or an analysis strategy that would help them to answer their question, and Rory made suggestions in verbal exchanges that helped students see how the work they had done and knowledge they had gained could help them get to the next stage in the project. As Wagner observed, students learn in projects on a need-to-know basis: "They won't care [about data analysis strategies] until they have to do it." But when faced with taking their project to the next step, they more readily recognized the value of Wagner's insights.

CONCLUSION

Project-based science teaching and learning involve complex role changes for teachers and students. Too often, the complex work teachers perform as facilitators and guides for project-based student work is left mysterious. In this chapter, we described a dialogue sequence for transformative communication, one productive discourse strategy teachers can use in the role of facilitator. We also elaborated concrete cases in which this strategy was used successfully to help students accomplish science inquiry with more sophistication than they could originally conceive. When teachers set up project activities that challenge and scaffold students in carrying out authentic elements of science practice (National Research Council, 2000; O'Neill & Polman, 2004), the students will develop numerous seeds of scientifically interesting and rigorous inquiry. But as the learning paradox teaches us, the seeds alone do not have what is needed to enable the production of new knowledge. The environment the seeds are planted in must be fertile. The seeds need the sunlight of teacher's more expert vision to reveal their potential, and the soil and water of interaction between teacher and students, before they will sprout to reach their full potential.

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NOTE

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

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