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CHAPTER 3

Language and Science Learning

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In a 1998 contribution to the *International Handbook of Science Education*, Clive Sutton used the writings of Faraday, Boyle, Harvey, and others to compare the language found in historical documents with the ways in which science is represented in contemporary textbooks and classrooms. In Michael Faraday's letters to scientific contemporaries, Sutton found a voice that was personal and overtly persuasive, eschewing the third-person, "stick to the facts" register with which schoolchildren today are commonly taught to write laboratory reports. Drawing on science studies by Bazerman (1988), Lemke (1990), Medawar (1974), Shapin & Schaffer (1985), and others, Sutton (1998) recommended reduced emphasis in science education on language as a means of transmitting information and greater emphasis on language as an interpretive system of sense-making.

Only 5 years later, a survey of recent literature on language and science education demonstrates both the utility of Sutton's framework and the potential for its expansion. An overall healthy growth of that literature masks some interesting trends within that literature. Consider, for example, Figure 3.1, which plots the average annual publication rate of documents with keywords *Science Education*, *Language*, and either *Concept Formation* or *Culture*. Following a period of stability from about 1980 to 1995, publications related to *Concept Formation* have declined in number, while *Culture* has increased.[1] Trends like this reflect changes in the field regard-

1. For the sake of the narrative, I have simplified my description of the method in which the Figure 3.1 data were generated. The set described in the prose as (kw = "Science Education" AND "Language") is actually more accurately represented as ((kw = "Science Education" OR "Science Instruction") – (kw = "Programming" OR "Programing")) AND "Language". Use of the longer specification eliminated almost all of the numerous studies of computer programming (or ERIC's earlier spelling, "programing"), few of which were concerned with language as a means of oral or written communication between teachers and students engaged in science teaching and learning. My choice of keywords (and their linking algebra) followed a quantitative analysis of all ERIC citations in the aforementioned set from 1975–2002 (the most recent year that is reasonably completely indexed) and from study of the frequency distributions by date of the first 10 keyword descriptors of each of the citations. However, the data in Figure 3.1 are offered for heuristic purposes only; this is not a statistical argument!

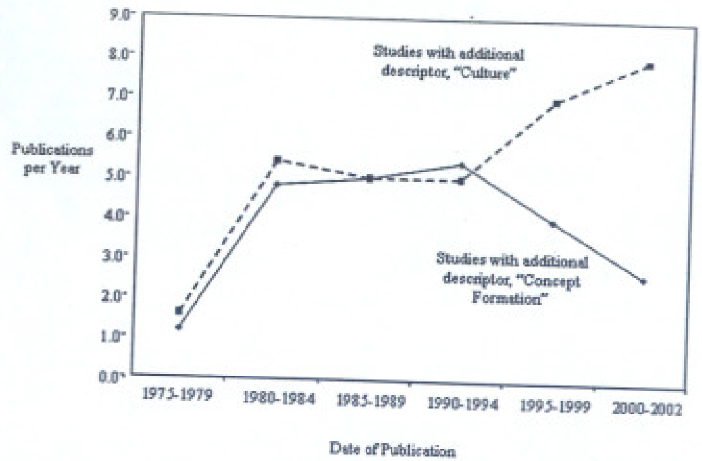

FIGURE 3–1. ERIC citation rates for publications with keywords *Science Education, Language,* and either *Culture* or *Concept Formation,* by date.

ing what it means to learn (and to teach) science. Following a shift in emphasis from learning as individual cognitive growth to learning as individual cognitive growth in social settings, research increasingly views language as more than just a social means to individual ends.

The first section of this chapter discusses the origins of much of this newer research, beginning with four schools of thought. The roots of these perspectives grow together in a number of ways, but they also emphasize different things. The second section of this chapter reviews recent research concerning language and science learning, building to a conceptual framework based on Sutton's earlier work. The reader should note that a detailed perspective on specific studies of spoken and written discourse in science classrooms is provided by Greg Kelly in Chapter 16. A comprehensive recent review of science literacy by Yore, Bisanz, and Hand (2003) deals more extensively than I do here with the important role of writing in science learning. My aim here is to propose a framework informed by theoretical issues that are historically significant or productively emerging in science education, without covering the same ground in the same way. To do this, I first identify some of the contributions of four productive contemporary approaches to studying the role of language in science learning: the Vygotskian perspective, conceptual change theory, sociolinguistics, and situated learning.

ORIGINS OF CONTEMPORARY RESEARCH ON LANGUAGE AND LEARNING

Vygotsky

Lev Vygotsky was a contemporary of the young Piaget and closely followed his work. He concurred with many, but not all, of Piaget's conclusions. Vygotsky's

most compelling contribution to science education is probably *Thought and Language* (1934/1986). Although the book says practically nothing about pedagogy, it has been productively probed for its educational implications, which are significant (Howe, 1996; Wertsch, 1985, 1991). Vygotsky distinguished between spontaneous and scientific thinking. Spontaneous concepts arise in a child's everyday experience and begin with egocentric speech, often in the company of others. Eventually, vocalized speech is internalized, evolving into inner speech. According to this view, spoken language precedes conceptualization in everyday life. Meaning actually follows speech.

According to Vygotsky, scientific thinking is special because new scientific concepts generally arise from work within a formal conceptual structure (which may be explicitly taught). Consequently, science learning is a process of moving from the linguistically abstract to the concrete, not vice versa. Children learn spontaneous concepts (e.g., what a bowl is) from their everyday experiences. Scientific concepts (e.g., what photosynthesis is) are often invisible, abstract, or otherwise inaccessible. One oft-overlooked instructional implication of this perspective is that some scientific concepts may never arise from hands-on experience, no matter how creative or time-consuming that experience may be.

Vygotsky's "zone of proximal development" (ZPD) has been used extensively by researchers and educators. The idea is appealing: The trajectory of future learning can be predicted by comparing a child's work alone with his or her work in the company of a more knowledgeable teacher or peer. Numerous studies have translated the ZPD concept into a pedagogical agenda: Engage learners in group tasks with others, on the grounds that the social setting will allow many students to stretch beyond the limits of their abilities, working alone.

Finally, in *Thought and Language,* Vygotsky noted that writing is linguistically distinct from and more demanding than speech. The developmental path of writing is more abstract, symbolic, and less likely to elicit (and be shaped by) feedback from others. A number of research and instructional projects have been built upon Vygotskian ideas, such as the Cognitive Acceleration through Science Education (CASE) project in Britain (Adey, 1999), research on elementary science instruction in Mexico (Candela, 1995), and the effects of computer-mediated communication in American science and math instruction (Charnitski & Harvey, 1999).

Some critics have charged that Vygotsky has been misappropriated for nefarious purposes like promoting sociocultural relativism, replacing formal instruction with useless hands-on experiences, and misinterpreting the ZPD as a bridge between everyday experience and scientific concepts. Vygotsky, argued Stuart Rowlands (2000), was an "out-and-out objectivist" who believed that theory precedes practice in science. Everyday experiences may be necessary for scientific concepts to develop, but they do not cause that development. Scientific ideas ascend from the abstract to the concrete (Rowlands, 2000; Rowlands, Graham, & Berry, 1999). In science there is always a critical need for formal instruction.

Conceptual Change Theory

Conceptual change theory (CCT) has long been an important paradigm in science education research. Building from work by Piaget (1929/1969) and Thomas Kuhn

(1970), the team of Posner, Strike, Hewson, and Gertzog (1982) outlined a model of science learning that accounts for the resistance of misconceptions to change and that foregrounds the interaction between individuals and the scientific communities (and theoretical perspectives) to which they are acculturated. From a sociolinguistic perspective, CCT is itself a fruitful research program; that is, it stimulates the generation of interesting questions. For example, Lavoie (1999) documented the positive effects of adding a prediction/discussion phase to the beginning of a learning cycle in secondary biology. Among the features of his experimental treatment was an insistence that students make their predictions explicit and that they publicly debate, modify, and reevaluate those predictions. The genesis of these steps from CCT is clear.

Constructivism has largely supplanted CCT in the science education research vernacular, despite the problem of its many different meanings. Nevertheless, CCT remains a viable theory and may prove—for social, philosophical, and methodological reasons—to be more long-lived. Fundamentally, constructivism is about individuals creating individual meanings, sometimes in social settings. Conceptual change theory emphasizes the congruence of individual understandings with public, often established, knowledge (see also Chapter 2, this volume). CCT also foregrounds the importance of epistemic communities (Kelly, 1997).

As Vygotsky's work is becoming more widely known, researchers and educators are seeking ways to extend CCT from the intramental to the intermental plane. Using an analysis of a chemistry lesson, Mortimer and Machado (2000), for example, discussed the evolution of their understandings of cognitive conflict (an individual, Piagetian construct) to one of public, discursive conflict, resolved dialogically. In recent years, the emphasis of many studies of conceptual development in science education has shifted from the investigation of individuals' cognitive schemata to studies of interactive discourse and the co-construction of concepts in natural language. This has required finding tools and methods better suited for documenting and analyzing the dynamics of spoken language in classrooms. This brings us to a third major approach to studying how language and learning are related: the sociolinguistic perspective.

Social Semiotics and Sociocultural Considerations

Lemke's *Talking Science* (1990), a field guide to analyzing the content of classroom discourse, clearly demonstrates the need to consider the context of spoken language. Although this principle is a sociolinguistic fundamental, Lemke drew most directly on what he labeled "social semiotics." Here and in later works (e.g., Lemke, 2001), he argued that meaning is derived in part from the cultures in which talk takes place, and that meaning-making is impeded when culture clashes arise between disciplinary cultures, as well as between more conventional social/economic/political/ethnic cultures. In fact, the science classroom sits on the border between competing cultures, such as the scientific community, which values open inquiry and disagreement, and the formal school community, which generally prefers quiet obedience. Lemke and others found that sociologies of science also offer useful tools for understanding the social work of scientists, from which implications for classroom practice can be drawn (Kelly, Carlsen, & Cunningham, 1993; Roth, 1995a).

We learn to communicate in different ways in different settings. Children who begin school without having been socialized to conventional forms of school communication may experience communicative failures that are interpreted as lack of aptitude or intelligence (Heath, 1983). Studies of language minority students demonstrate how the routine communicative expectations of majority teachers can be misinterpreted because of lack of teachers' understanding of the cultural norms and practices in their students' out-of-school lives (Au & Mason, 1983; Erickson & Mohatt, 1982). Our *discourse* consists of the words, gestures, and other signs that we use; our *Discourse* consists of all of the other things that help us make sense of language: "Different ways of thinking, acting, interacting, valuing, feeling, believing, and using symbols, tools, and objects" (Gee, 1999, p. 13). Learning may be easier when teachers strive for instructional congruence between the academic culture and the culture(s) of their students, modifying subject matter by using students' language and cultural experiences (Lee & Fradd, 1998).

Provocative but less thoroughly explored, cultural practices and language may be exploitable in addressing students' scientific misconceptions. Hewson and Hamlyn (1984) discovered that southern African Sotho and Tswana teens speak languages that predispose them to kinetic (particulate) rather than caloric (substance) views of heat. Potentially, this linguistic and cultural resource might help them avoid common misconceptions. Although later studies of Sotho college entrants could not corroborate this phenomenon (Lubben, Netshisaulu, & Campbell, 1999), further studies of the interaction of nonmajority language and science learning opportunities would be worthwhile.

Hogan and Corey (2001) provided an excellent example of classroom research from a sociocultural perspective. In addition to *Talking Science*, Groisman, Shapiro, and Willinsky (1991) offer a gentle introduction to the use of semiotics in science education research.

Situated Learning and Communities of Practice

Clearly, the concepts of situated learning, legitimate peripherality, cognitive apprenticeships, and communities of practice are having an important impact on science education research. Studies by Lave, Wenger, and others have given educational researchers much to think about and work with, even though the bulk of their work has been done in nonschool settings (Chaiklin & Lave, 1993; Lave & Wenger, 1992; Wenger, 1998). Studies of cognition in situ—of craftwork, midwifery, and other jobs—reveal how novices learn complex skills through participation in real work, initially as peripheral participants. One of the most exciting aspects of this literature is its suggestions that learning is not a process of internalizing knowledge, that it is not promoted by social activity; learning is social activity.

Wenger (1998) portrayed a claims-processing office as an environment in which work, interaction, and learning are inextricably linked. "Issues about language," Lave and Wenger (1992) wrote, "may well have more to do with legitimacy of participation . . . than they do with knowledge transmission. . . . Learning to become a legitimate participant in a community involves learning how to talk (and be silent) in the manner of full participants" (p. 105).

In some cultures and for many crafts, conventional didactic instruction would be culturally inappropriate (Jordan, 1989) and less suitable than the traditional apprenticeship model.

Roth (1995b) applied many of these ideas in his analysis of science classroom practices. Of particular interest are his demonstrations of the transformation of gestures, inscriptions, and other phenomena in shaping concepts in the public sphere, a paralinguistic process evocative of Vygotsky. In the laboratory setting, gestures, for example, may function less as evidence of conceptual understanding than as a tool for co-constructing concepts with one's laboratory partners (Roth, 2001). The utility of viewing science learning in a social fashion has also been demonstrated in studies of adult learners. For example, in an ethnographic study that took place over several years, Bowen and Roth (2002) identified the different contributions to the education of ecologists that take place in formal and informal settings, and demonstrated the importance of stories and other informal communications in shaping novices' understandings. They also argued that storytelling contributes to social cohesion in scientific communities. In other words, not only do communities of practice provide a context and a means for learning science through language, but informal language—often superficially off-task—functions to help create functioning communities. The model of apprenticeship embedded in Lave's work can also be used productively to study the learning of novice teachers in settings where they coteach, and studies conducted with this lens have the potential to inform teacher education, viewing the learning of novice and experts as reciprocal (Roth & Tobin, 2001).

TOWARD A REVISED FRAMEWORK FOR THE ROLE OF LANGUAGE IN SCIENCE EDUCATION

My goal in this section is to extend and update Sutton's 1998 framework concerning the role and function of language in science teaching and learning, focusing on four features: (a) what a speaker appears to be doing, (b) what listeners think that they are doing, (c) how language is thought to work in learning, and (d) how language is thought to work in scientific discovery.

What a Speaker Appears to Be Doing

Controlling discourse. Although of course students often speak and write, traditional teaching is characterized by an asymmetry of conversational rights that favors the teacher. Teacher questions, for example, both reflect a teacher's authority and reinforce it (Carlsen, 1991a). Questions assert sociolinguistic power (Mishler, 1978), and when teachers find themselves discussing unfamiliar subject matter, they may rely upon questioning to prevent the topic of discussion from wandering into uncomfortable territory (Carlsen, 1991b). This creates what Driver (1983) labeled as the science teachers' dilemma: teaching science as a process of inquiry and as an accepted body of knowledge poses a constant linguistic challenge. Driver wrote, "On the one hand pupils are expected to explore a phenomenon for themselves, collect data and make inferences based upon it; on the other hand this process is intended to lead to the currently accepted law or principle" (p. 3). We expect teachers

to invite students to construct meaning, but we hold them accountable for the construction of the right meaning.

Fortunately, most students cooperate in the most common patterns of classroom discourse, such as variations on the Initiation-Response-Evaluation (IRE) triad that have been described by Mehan (1979), Lemke, and many others. Viewed as a language game (Wittgenstein, 1967), the IRE is both a mechanism of control and a cultural tool (Wertsch, 1991). Unfortunately, even well-intentioned control of the direction of science talk may result in a conflation of the teacher's authority as an expert with her authority as the person in charge (Carlsen, 1997; Russell, 1983; Toulmin, 1958). The resulting discourse may suggest to students that the nature of science is more certain and less susceptible to challenge than it really is. There are other cognitive hazards. Wilson (1999) cautioned: "[If] engagement in epistemic tasks in discourse is important in the construction of abstract declarative knowledge and conceptual understanding, then students may face disadvantages in classrooms in which discursive practices are teacher controlled and dominated by extensive triadic dialogue about knowledge claims provided for students by the teacher or the text" (p. 1080).

In more open-ended project-based science work, students may not understand the rules, and both order and learning may suffer. There are hazards to unguided discovery (Rogoff, 1994), but teachers who know how to play language games can transform original student moves and open them to extension, elaboration, or critique (Polman & Pea, 2001). But it is a balancing act. Hogan, Nastasi, and Pressley (1999) found that teacher-directed discourse was most effective in promoting higher-order reasoning and higher-quality explanations, but discussions among students were more generative and exploratory. Other work on the balance between restricting or expanding control has been informed by Vygotsky's ZPD concept (e.g., Blanton, Westbrook, & Carter, 2001).

Creating opportunities for meaning-making. On a more constructive note, teachers facilitate linguistic meaning-making in many ways. Kelly and his collaborators documented the work of a science non-expert teaching science to third graders. Instead of closing down the conversation, the teacher successfully modeled and directed scientific discourse, leading her students to define science in their local context (Crawford, Kelly, & Brown, 2000).

> To become a member of a community (e.g., science classroom or research laboratory) who acts in socially appropriate ways (e.g., one who adheres to genre conventions when speaking and writeing), one must first understand the social practices of a community, that is, what counts as a valid description, explanation, inference, etc. (p. 626).

The research group found similar practices in a high school physics classroom: a teacher framing activities and coordinating sociocultural practices, thus leading his students to appropriate scientific discourse (Kelly & Chen, 1999). Coherent and jointly constructed discourse resulted in the creation of public, sociolinguistic meaning.

Of course, local meaning is not the same as scientific fact: Gravity cannot be dismissed through a classroom conversation. Science is epistemologically distinct in its empirical approaches, its forms of argument, and the demonstrable productivity of concepts and theories that would never arise spontaneously in a school setting (quantum physics, for example). Recalling Vygotsky, scientific concepts often grow from the abstract to the concrete. They are useful because they are decontextualized (Rowlands, 2000). Approached from a different direction, scientific experiments yield facts through social processes of inscription, translation, and the ultimate removal of "weasel words" that relate the empirical *who, what, when, where*, and *how* (Latour & Woolgar, 1986). The approaches are different, but the outcomes are the same: useful facts stripped from the particulars of their construction.

What Listeners Think They Are Doing

In inquiry-oriented classrooms, students often work in groups, and their work can be viewed as contributing to the solution of shared problems. Students can learn science and *about* science when their communication takes place through online discussions (Hoadley & Linn, 2000), computer-mediated peer review (Trautmann et al., 2003), and other modalities, but group work usually takes place face to face. Without the teacher present, the rules of the language game are altered, and the new rules must be understood by all in order to make progress. Communicative competence entails knowing how to take turns without the teacher's direction, how to hold (and yield) the floor, and how to make sense to (and of) others. These tasks are inevitably complicated by speaker differences of gender, culture, ethnicity, and so on (Philips, 1972).

The substance of science talk can be evaluated in a number of ways. Geddis (1998), for example, developed a multidimensional method for gauging the quality of discourse. High-quality discourse includes practices like giving reasons for assertions and demonstrating intellectual independence from the teacher's authority. Hogan (1999) identified metacognition as an essential element in group inquiry and conducted a study in which students in experimental classes received training in metacognition and cognitive strategies for group work. The intervention resulted in improvements in students' knowledge about metacognition and collaborative reasoning, but no difference was found in the experimental and control groups' actual collaborative behaviors. Nevertheless, the success of metacognitive strategies in individual students' learning suggests that further work along these lines may be valuable.

Epistemological beliefs may not change easily. In one study, 4 weeks of substantive inquiry about evolution produced little shift in students' epistemological frameworks, which were found to be unstable and ill-defined. The investigators in that study advocated explicit epistemic discourse coupled with inquiry (Sandoval & Morrison, 2003).

In a study of college engineering students, Kittleson and Southerland (2004) found that concept negotiation was rare, even when the instructor structured the task to promote that process. Clearly, success in channeling student discourse into productive knowledge construction is a pedagogical goal that demands much more work.

How Language Works in Learning

Making meaning. The Sapir-Whorf hypothesis (Whorf, 1956), now largely discredited, proposed that language shapes human cognition in profound ways, so that a person's native language would shape how she perceived the world. Today it is

commonly assumed by linguists that our brains are wired for language (although the details remain in dispute, such as Chomsky's (1972) theory of a universal grammar). Why then is culture—and the signifying systems that culture embodies—so important in meaning-making? From a sociocultural perspective, learning involves appropriating and using intellectual and practical tools. Much of what a student learns comes not from direct experience, but from texts that are organized to tell a disciplinary story. "From a sociocultural perspective, the use of texts as the prime vehicle for communicating knowledge can be seen as a further step in the adoption of experience-distant accounting practices for understanding the world" (Säljö, 1998, p. 49). Human knowledge is discursive in nature, reproduced through language and artifacts in social institutions like schools.

> The knowledge produced within these discourses does not remain inside the heads of individuals. . . . Rather, knowledge emerges as properties of tools and socially organized practices in which individuals participate, and which by necessity are ideological in nature—without values there can be no knowledge. . . . Knowledge is fundamentally argumentative in nature; it moves the world rather than reflects it. (Säljö, p. 53)

Wong and Pugh (2001) observed that we promote the teaching of concepts rather than facts because concepts are more integrative and thus more powerful in science. Cognitive perspectives emphasize thinking; sociocognitive perspectives highlight the role of language in stimulating and supporting thinking. John Dewey emphasized ideas rather than concepts, and being, the combination of cognition and action:

> Dewey's emphasis on being, rather than cognition, reveals an epistemological stance that locates meaning neither in the mind of the learner nor in the surrounding environment. Instead, meaning is a transactive phenomenon: it exists only in the situation created in interaction between person and world. . . . To some readers, ideas and concepts may seem synonymous and we admit that Dewey's use of the term *idea* (along with other terms), although precise, is often confusing. To begin, concepts are something that students learn: To understand is to have an accurate representation of it and to be able to apply it appropriately. The goal of conceptually oriented teaching is the construction of accurate, meaningful representations. By contrast, ideas are something that seizes students and transforms them. The goal of ideas-based teaching is to help students to be taken by an idea and to live with it, to be with it in their world. (Wong & Pugh, pp. 324–325)

Of course, meaning-making is not the only function of language in the classroom. Discourse has two distinct functions in science education: generating meaning (its generative function) and conveying meaning (its authoritative function) (McDonald & Abell, 2002; Mortimer & Machado, 2000).

Representing knowledge. A number of researchers have studied how knowledge is represented in science education settings and have developed tools that provide insights into how language functions in learning. For example, in a cross-cultural study of English and Asian-speaking children, Curtis and Millar (1988) developed a method for representing students' knowledge about scientific concepts by classifying ideas generated in a writing task. Concept mapping in diverse forms remains a popular tool for representing the relationships among concepts (Fisher, Wandersee, & Moody, 2000), and the use of concept maps has been facilitated by several different computer tools. Semantic networks, ideational networks, and other graphical diagrams have been found to be useful diagnostically and to stimulate science talk with language minority students (Anderson, Randle, & Covotsos, 2001; Duran, Dugan, & Weffer, 1998).

Building upon work on situated learning and the sociology of science, Roth (1995a) described a number of cases of both individual and collaborative knowledge construction. The assignment of group work and the use of conscription devices such as concept maps helped create conditions in which "students had to negotiate the meanings of concept labels or future courses of action. During these negotiations they externalized and objectivized their understandings so that they were open not only to public scrutiny but also to critical self-reflection. In this process, students negotiated prior understandings and invented new and not-yet experienced connections between concepts" (p. 267).

In related studies, Roth and his colleagues described the semiotic significance of graphs as signs representing objects and processes (Roth, Bowen, & Masciotra, 2002), as well as the role of gestures and rough-draft talk, which they believe support the subsequent evolution of more structured talk, iconic objects, and eventually abstract communication tools, including symbols and writing (Roth & Lawless, 2002). "Gestures are a medium on which language can piggyback in its development" (Roth & Welzel, 2001). The authors suggested that, because gestures frequently are used to refer to materials in the laboratory, students should not be sent home to write laboratory reports until they have had the opportunity to discuss the complex conceptual issues explored in the teaching laboratory.

Cultural Considerations

The interaction of culture, language, and schooling has been a productive focus of research in a number of disciplines. A great deal is known, for example, about how and why differences between the cultures and languages of school and home can be problematic for students (Au & Mason, 1983; Shultz, Erickson, & Florio, 1982). Even among speakers of the same language, problems may arise if the home register does not match the privileged formal register of schools (Bernstein, 1961). The dynamics of communication between linguistic and ethnic minority and majority speakers continues to be an active and interesting area of work (see, e.g., Moje, Collazo, Carrillo, & Marx, 2001; Stoddart, Pinal, Latzke, & Canaday, 2002). Lee's (1999) study of south Florida children's attributions of Hurricane Andrew demonstrated gender, socioeconomic, and ethnicity effects, not only with respect to what the children knew, but also where they got their information. Lee and Fradd (1996) emphasized that although culture may sometimes contribute to misconceptions, and that scientific practices like questioning and public skepticism may clash with some cultural norms, culture also provides metaphors and other linguistic resources that we are only beginning to understand.

Writing

Although my comments have focused primarily on spoken language, there is a growing literature on how writing functions in the development of knowledge. For example, Keys has shown how collaborative writing can enhance students' constructions of scientific concepts (Keys, 1994, 1999) and the quality of their reasoning (Keys, 1995). She and her colleagues developed a Science Writing Heuristic as an alternative to the traditional laboratory report and reported that it promotes students' generation of assertions from data; making connections among procedures, data, evidence, and claims; and metacognition (Keys, Hand, Prain, & Collins, 1999). Positive outcomes from interventions using diverse types of writing tasks have been reported, although the students themselves may not see writing as a tool for knowledge development (Prain & Hand, 1999).

Talking and writing yield different outcomes because of their different natures. Rivard and Straw (2000) noted:

> Talk is important for sharing, clarifying, and distributing scientific ideas among peers, while asking questions, hypothesizing, explaining, and formulating ideas together all appear to be important mechanisms during discussions. The use of writing appears to be important for refining and consolidating new ideas with prior knowledge. These two modalities appear to be dialectical: talk is social, divergent, and generative, whereas writing is personal, convergent, and reflective. (p. 588)

Both are important for doing science in classrooms: just as it is through the public processes of formal science that objectivity is pursued, via intersubjective means.

How Language Works in Science

Language is central to science. It is the medium through which claims are made and challenged, empirical methods and data are recorded, and the story of inquiry unfolds. Language is not just a vehicle for transmitting scientific information; the history of science reveals that analogies, for example, are a powerful conceptual resource for scientific discovery and understanding (Dörries, 2002). Scientific language is rich with specialized terms that have metaphorical origins (Sutton, 1992).

Compared with students, scientists, not surprisingly, hold much more sophisticated understandings about how to make knowledge claims from data. They are more likely to prioritize rhetorically the relationship between empirical evidence and conclusions, and they attribute this ability to their earlier socialization to science. In contrast, middle-school science students rely more upon their personal views to evaluate claims (Hogan & Maglienti, 2001). Nevertheless, scientists generally believe that the writing process involves knowledge telling, not knowledge building. Their writing tends to be narrowly focused on a specific genre, target audience, and approach (Yore, Hand, & Prain, 2002).

The experimental article is a specialized genre with an interesting history. For example, the detachment and emotionlessness of the form may have helped to reduce factionalism in science (Bazerman, 1988). Scientific writing is lexically dense because it is replete with colorful, invented words that reduce complex processes to singular identities (Halliday & Martin, 1993) (e.g., *photosynthesis* or *cellular automaton*). Also commonly invented are scientific discoveries, which are often reconstructed after the dust settles, fixed in time retrospectively by a scientific community (Brannigan, 1981; Woolgar, 1976). But the more startling the claim, the more likely it is that there will be dust to settle. Discursive consensus in science is not as clean or as common as is generally believed. Intellectual divergence is normal, and the interpretations of scientists may vary with their own sociocultural context (Mulkay, 1991).

Nevertheless, it would be an unusual scientific research manuscript that began with a personal statement about the investigator's gender, race, religion, or ethnicity. The official registers of science do not document an investigator's personal and social values, beliefs, and commitments, because, after all, facts speak for themselves. The status of science is attributable in part to persistent myths. As Helen Longino (1990) noted, science achieves objectivity through social means. We ought to be willing to talk about it. Furthermore, students of science need those opportunities as well. Longino (2002) offered four criteria for effective scientific discourse: (a) public venues for the critical review of methods, facts, and the interpretation of data; (b) an expectation of uptake—that investigators will respond to the substance of public criticism; (c) the existence of public standards for evaluating claims, such as the criterion that claims refer specifically to data in ways that can be generally understood; and (d) that discourse occurs in a context of tempered intellectual equality—one that recognizes inevitable differences in participants' knowledge without denying the less knowledgeable opportunities to challenge.

CONCLUSION AND IMPLICATIONS

Table 3.1 updates and extends Sutton's (1998) framework. To his two articulations of the role of language—1. a system for transmitting information, and 2. an interpretive system for making sense of experience—I have added a third column: a tool for participation in communities of practice. This third perspective reflects a contemporary emphasis on learning as a social accomplishment. Formal science is much more than Scientist A convincing Scientist B that X is true. Scientist A's conception of X is almost always the product of extensive work in a local community of practice (such as a lab group), and the proposed definition of X may have emerged there from a complex iteration of experiments, inscriptions, translations, conversations, arguments, informal talks, feedback from peers outside the group, methodological training, new experiments, etc. (see Knorr-Cetina, 1983). At the broader disciplinary level, Scientist A and Scientist B probably share assumptions and understandings that are not recognized by others. Scientist C (and her group) may be exploring the same scientific terrain with very different tools and assumptions, leading to very different conclusions. Eventually, an agonistic struggle is likely, but as Longino (1990) notes, that is the point of science. It is in the expectation and practice of public argument that science progresses. Conflict is not only permissible, it is necessary. This does not mean that science is nothing more than mob psychology. Usually arguments must be based on observable phenomena, but what counts as an observation is something we agree to agree about.

An important problem for researchers using sociocultural tools—at least in the United States—is that we are working in an era of accountability, and political forces demand "objective" measures of student learning and educational productivity. Today's emphasis on individual standardized testing is based on an assumption that learning is an individual accomplishment. One implication of a sociocultural perspective is that we need to develop better tools for evaluating learning in complex social environments. Affordable new tools for video recording and analysis

TABLE 3.1.
Changing Perspectives on the Role of Language in Science and Science Teaching

*Characteristic**	*Role of Language*		
	A system for transmitting information (Sutton, 1998)	*An interpretive system for making sense of experience (Sutton, 1998)*	*A tool for participation in communities of practice*
1 What the speaker or writer appears to be doing.	Describing, telling, reporting.	Persuading, suggesting, ex-ploring, figuring.	Contributing to the solution of a shared problem.
2 What listeners or readers think that they are doing.	Receiving, noting, accumulating.	Making sense of another person's intended meaning.	Contributing to the solution of a shared problem.
3 How language is thought to work in learning.	Clear transmission from teacher to learner; importance of teacher's speech.	Re-expression of ideas by learner; importance of learner's speech.	Achievement of a shared understanding. Learning and language as social accomplishments.
4 How language is thought to work in scientific discovery.	We find a fact, label it, and report it to others. Words stand for things.	Our choices of words influence how we and others see things: highlighting some features and ignoring others.	Language is used to persuade, and "discovery" is often constructed only retrospectively.

**Note.* "Characteristic" labels and the next two columns are based on Sutton (1998).

offer great potential for helping researchers study language as an educational outcome, not just a means. However, few science education researchers have had formal training in sociolinguistics; after all, their undergraduate training tends to occur in the sciences. It would benefit our community to support the development of graduate training programs that teach future researchers skills to work with linguistic data.

A related implication is that we need to publicly challenge the prevailing view of learning as an individual accomplishment. We must challenge that view with policymakers and parents as well as within our own research community. Strategically, support for the development of social methods of assessment is likely to require convincing the public of the social nature of real science and demonstrating that the attrition of talent from the scientific work force is in part the result of practices that represent science as the individual accomplishment of unambiguous understandings.

New tools notwithstanding, collecting data in the form of natural language is extraordinarily time-consuming and expensive. Because our community lacks useful standards for the collection, transcription, analysis, cataloging, and use of sociolinguistic data, data collected in one study are unlikely to be used again. Compounding this problem, university institutional review boards today often seek assurances that the use of video recording in precollege classrooms is minimized and that recordings are locked away or destroyed after research is conducted. The development of standards for sociolinguistic analysis in science education would be a useful effort. These standards should certainly be informed by standards in related fields. However, our needs are likely to be unique, given the gestures and other signs, texts and inscriptions, specialized tools, and shifting group composition that characterize science learning environments. We are likely to be best served by systems that could be used responsibly by researchers who have not had extensive training in linguistics. As part of such an initiative, it would be useful to develop conventions for metadata production and cataloging (e.g., through the Open Archives Initiative, www.openarchives.org), as well as mechanisms for protecting human subjects without the necessity of locking data away from other researchers. A corpus of such data would be useful in both future research and for training new researchers.

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CHAPTER 4

Attitudinal and Motivational Constructs in Science Learning

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This chapter examines the attitudinal and motivational constructs that are closely linked to science learning. First, we present a rationale for the study of attitudes and motivation in the context of science learning. We then discuss the history of attitude research in science education, define constructs prominent in this research, and review recent attitude research findings. We review research methods and instruments, students' attitudes toward science and factors that influence them, and interventions to change students' attitudes. Next, we focus on motivation, highlighting the historical background of theoretical orientations and discussing research on constructs of particular relevance to science education researchers. We conclude our chapter by offering recommendations for future research involving attitudinal and motivational constructs, noting implications for policy and practice.

At this point, we wish to acknowledge that it is impossible within the scope of this chapter to evaluate every significant study in the field of science education that addresses attitudinal or motivational constructs. Our goal is to provide the reader with an overview of the role these constructs play in science learning through strategic sampling of the relevant research.

Throughout this chapter we use the term *construct* to mean a scientific concept that represents a hypothesized psychological function (Snow, Corno, & Jackson, 1996). Attitudinal and motivational constructs are used to account for and infer patterns of science-related thinking, emotion, and action. They tend to be relatively enduring within a person, but have the potential to change. According to Snow et al. (1996), a construct identifies a unique dimension on which all persons differ by degree and should be represented by more than one kind of data.

Effective science instruction has the potential to improve attitudes toward science and heighten the motivation to learn science. Hands-on science activities, lab-