EXPLORING THE ROLE OF INQUIRY AND REFLECTION IN SHARED SENSE-MAKING IN AN INQUIRY-BASED SCIENCE CLASSROOM: TOWARD A THEORY OF DISTRIBUTED SHARED SENSE-MAKING

Barbara G. Ladewski
Joseph S. Krajcik
Center for Highly Interactive Classrooms, Curricula, and Computing in Education
School of Education
University of Michigan

Annemarie Sullivan Palincsar
Guided Inquiry Supporting Multiple Literacies
School of Education
University of Michigan

Abstract. Despite considerable attention to inquiry and reflection in the literatures of science education and teacher education/professional development over the past century, few theoretical or analytical tools exist to compare/contrast these processes, or to characterize their development, within a naturalistic classroom context. In the current research study, we develop a model of shared sense-making that attempts to integrate processes of inquiry and reflection, and systems of shared sense-making and mental models of those systems, into a single coherent theoretical framework. Using the model of shared sense-making as an interpretive lens, we then develop a qualitative case study that explores empirically teacher-student shared sense-making over the course of a year of scaffolded introduction to inquiry-based science instruction.

Theoretical arguments and empirical findings both suggest that conceptualizing inquiry and reflection as two interactive coherence processes within a model of shared sense-making provides a rich interpretive framework for exploring developing understanding/sense-making in the classroom. Results further suggest that perspectival shifts play an important role in that developing shared sense-making. In particular, perspectival shifts among doing, thinking, and thinking about thinking, and among opening to consider multiple possible interpretations and closing to examine a particular interpretation in detail, seem to play a central role in inquiry and reflection. Conceptualizing teaching/learning as shared sense-making rather than individual teacher activity or student learning has important implications for both science education and teacher education/professional development.

Introduction

Successive reform efforts in science education over the last century have repeatedly identified “inquiry” as one of the fundamental processes involved in constructing

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scientific ideas (AAAS, 1990, 1993, 2000; Dewey, 1910/1933, 1938; NRC, 1996, 2000, 2007; Schwab, 1966). At the same time, research in teacher education has repeatedly identified "reflection" as one of the central processes involved in decision-making within the ill-structured domains of professional practice (Rogers, 2002; Schön, 1983, 1987; Shulman, 1988). However, despite the considerable attention these two constructs have received within their respective fields, we know little about the nature of these constructs as they actually play out within naturalistic classroom contexts, and equally little about possible developmental progressions or potential interrelationships among the two constructs.

Science and Inquiry

Although reform efforts in science education have consistently identified inquiry as one of the critical elements of effective science teaching and learning (AAAS, 1990, 1993, 2000; Dewey, 1910/1933, 1938; NRC, 1996, 2000, 2007; Schwab, 1966), teaching has changed very little in science classrooms during that period—teacher-led lectures; textbook-based curricula; and memorizing facts and formulae have continued as the predominant instructional activities in most science classrooms (Anderson & Smith, 1987; NCES, 2004; Weiss, 1997). When changes in instruction have been attempted, the exploration of substantive scientific ideas/relationships has often been reduced to (a) "activity-based" instruction focusing on disconnected "hands-on" activities and/or prescribed laboratory procedures; or (b) "discovery-based" instruction focusing on unguided student exploration (Anderson & Smith, 1987). Why has fostering student understanding of scientific inquiry and facilitating meaningful student exploration of substantive scientific ideas/relationships proven to be such an elusive goal? Why has more than a century of effort in K-12 educational research and practice, curriculum and instruction, teacher education and teacher professional development, been so ineffective in fostering development of inquiry in K-12 classrooms *on a large scale*?

It seems important to explore these questions with an eye to the broader sociocultural context, as well as from the perspective of the challenges faced by individual teachers within particular instructional contexts. Joseph Schwab (1966) proposed that some of the key challenges teachers face may in fact arise from a fundamental contradiction between the "habits of mind" fostered by traditional American public education and the habits of mind required for inquiry. Schwab claimed that the K-12 educational system in the United States was originally structured to disseminate a common culture to the masses, not to support the capacity to inquire. As a result, few teachers in our K-12 classrooms have had the opportunity to engage in sustained inquiry themselves:

> We continue to route our publics through an indoctrinational program of unquestioned dogma. What is more, we now route most members of our elites, including many of our scientists and teachers, through a similar inculcation, permitting only a few men [sic] in each generation to push past its doctrinal barriers into the regions of reflection by sheer force of skeptical intelligence. (Schwab, 1966, p. 8)

Schwab proposed a dramatic change in the culture of American public education—our educational institutions should transform themselves from institutions structured to disseminate a common culture to institutions designed to foster the flexible analytic and synthetic ways of thinking needed to keep pace with (and shape) a rapidly changing world.

However, Schwab's proposal seems to present a dilemma—how does a transformation to inquiry thinking take place, when it may be inquiry thinking itself that is required to initiate and sustain such a change in thinking processes? How can institutions that were not designed to foster inquiry be transformed to do that task by teachers and administrators who may never have engaged in inquiry and may not have a vision of what inquiry looks like in the classroom?

The National Research Council (2007) has completed a comprehensive study of current research in science education. The report identifies four interrelated strands that define scientific proficiency for grades K through 8:

- Strand 1: Know, use and interpret scientific explanations of the natural world;
- Strand 2: Generate and evaluate scientific evidence and explanations;
- Strand 3: Understand the nature and development of scientific knowledge;
- Strand 4: Participate productively in scientific practices and discourse.

(NRC, 2007, p. 37)

The four strands clearly frame the goals of instruction. But, what is the process by which teachers and administrators, and eventually students, can be supported to meet these goals?

Has our research about inquiry helped develop a vision of what is unique about inquiry thinking, and specifically a vision of what is unique about inquiry thinking as it develops in the classroom, so that teachers and administrators have the tools to differentiate between substantive inquiry and other types of activity, such as "hands-on" activities or "discovery-based" learning? Has our research about inquiry helped to develop a vision of possible learning progressions as students (and teachers) develop an understanding of inquiry? What tools do we have to characterize teacher-student interactions in the classroom, in order to develop an in-depth vision of the process of inquiry as it develops in a classroom context?

Teacher Education and Reflection

While scientists and science educators were examining the central role of inquiry in making sense of real-world phenomena, teacher educators were pursuing a parallel thread of research exploring the central role of reflection in making sense of the dilemmas of professional practice. Donald Schön (1983) described a crisis of confidence in the professions precipitated by a mismatch between the canons of professional knowledge and the complexities, uncertainties, and values conflicts characteristic of a rapidly changing world of professional practice. Schön claimed that such conditions have led in some professions to "professional pluralism"—that is, practitioners are presented with competing views regarding appropriate professional practice and are provided with little guidance regarding how to choose between those differing views.

To understand the tasks of professionals operating within this world of indeterminacy and value conflict, Schön proposed differentiating the "naming" and "framing" of problem *setting* from the process of problem *solving*:

> …with this emphasis on problem solving, we ignore problem *setting*, the process by which we define the decision to be made, the ends to be achieved, the means which may be chosen. In real-world practice, problems do not present themselves to the practitioner as givens. They must be constructed from the materials of problematic situations which are puzzling, troubling, and uncertain…. Problem setting is a process in which, interactively, we *name* the things to which we will attend and *frame* the context in which we will attend to them. (p. 40)

Schön further proposed that a practitioner's continual redefinition of a problematic practice situation—through successively naming the things she will attend to and framing the context in which she will attend to them—defines the complementary thinking processes of *reflection-in-action* (1983, 1987) and *reflection-on-action* (1987). Schön proposed that these were the processes a thoughtful practitioner could use to adapt ever-changing professional knowledge to the ever-changing complexities, uncertainties, and values conflicts of real-world professional practice.

Once again, however, the question remains—what exactly does reflection look like as it plays out in practice? What differentiates reflection from other types of thinking, such as recall? And, what (if anything) differentiates reflection from inquiry?

Inquiry and Reflection: A Theoretical and Empirical Exploration

The current paper explores such questions theoretically and empirically. Because the two strands of research exploring inquiry and reflection converge in the science classroom, the science classroom provides a particularly rich context for exploring the nature of these processes as they play out in a real-world context. Theoretically, we develop a sociocultural model of shared sense-making to characterize teacher-student interactions in the classroom, focusing on teacher-student interaction as the unit of analysis, rather than using a more traditional lens of teacher enactment or student learning alone. Empirically, we use the model of shared sense-making as an interpretive framework to examine developing teacher-student interactions over the course of a year of a middle-school teacher (Connie) and her students' scaffolded introduction to a form of inquiry-based science instruction called project-based science (Blumenfeld et al., 1991; Krajcik, Blumenfeld, Marx, & Soloway, 1994; Marx, Blumenfeld, Krajcik, & Soloway, 1997). Project-based science provides a particularly rich context for exploring these questions because of its focus on developing a variety of instructional contexts to support teacher-student exploration—including opportunities to engage in first-hand investigations and opportunities to use scientific ideas to make sense of real-world issues.

Methods

The Context

The current research study was situated within a larger research project that explored issues surrounding understanding, planning, and enactment of project-based science and design of professional development contexts to scaffold that learning. Results from the larger research project have been documented in a number of previous publications (Blumenfeld, Krajcik, Marx, & Soloway, 1994; Krajcik et al., 1994; Ladewski, Krajcik, & Harvey, 1994; Marx et al., 1994). See Ladewski (2006) for a complete description of the research context.

School and Classroom Context

The site for the current research study was a middle-school serving approximately 600 students located in a small, racially and socioeconomically diverse district in southeastern Michigan. The school was departmentalized by subject matter in the seventh and eighth grades; sixth-grade teachers belonged to an interdisciplinary sixth-grade department. Connie was a member of a three-person 6th-grade team and taught three 6th-grade science classes.

Connie's science classes were large (31-33 students) and heterogeneous with respect to achievement. The classes were scheduled in 45-minute back-to-back periods (2nd, 3rd, and 4th hours), with little time for set-up or clean-up between classes and with almost no flexibility to extend an activity beyond the allotted 45-minute class period. Connie's classroom was not particularly well-designed for teaching inquiry-based science—it was not equipped with either a teacher demonstration table or student lab tables, had minimal counter and storage space, and during Year 1, did not have either a water source or a drain. Thus, Connie was faced with many of the same procedural challenges to engaging in investigative science instruction that are typical of middle school classrooms across the country--large class sizes, rigid class schedules, limited access to laboratory facilities, little money to purchase equipment or materials.

Connie's educational background included a bachelor's degree in science education and K-12 teaching certification; she had four years experience teaching sixth grade when the research project began.

Instructional and Curricular Context

This study examines Connie and her students' classroom interactions as they were engaged in a year-long scaffolded introduction to a form of inquiry-based science instruction called project-based science. Project-based science is characterized by multi-faceted, open-ended learning environments designed to help students develop more integrated understandings of science concepts as they explore authentic meaningful real-world questions over an extended period of time. Project-based learning environments: (a) are anchored by authentic, real-world questions or problem areas that provide a meaningful context for exploring substantive scientific ideas; (b) provide opportunities for students to carry out investigations, in which they ask their own questions, make predictions, gather and interpret data, draw conclusions, and frame real-world recommendations; (c) provide opportunities for students to construct artifacts that represent students' emerging understandings of substantive scientific ideas; (d) foster the development of communities of inquiry, in which students, teachers, and members of the larger community collaborate about the question or problem area; and (e) promote the use of cognitive tools, including computing and telecommunication technologies, to explore the question or problem area (Krajcik et al., 1994).

During Year 1, Connie and her students carried out two six- to eight-week project-based units—during the fall semester, the National Geographic Kids Network project entitled *What's in Our Water?* (National Geographic Kids Network, 1991); and during the winter semester, a similar National Geographic Kids Network project entitled *Acid Rain* (National Geographic Kids Network, 1989). Carrying out two similar projects over the course of the year provided the opportunity to compare/contrast classroom interactions for different instructional activities within one project and for similar instructional activities across both projects.

Data Sources and Analytical Methods

An interpretive case study comprised of "telling" mini-cases (Knobel, 1996) was developed to capture both the subtle nuances of teacher-student interactions at a particular moment in time and also the change in interactions over extended time.

Primary data sources used in developing the case study included videotaped and transcribed recordings of nine key lessons—four 45-minute lessons from each of the two project-based units during Year 1, as well as a culminating end-of-year student-designed investigation. Other data sources—including a rich set of informal conversations during enactment and teacher semi-structured interviews after enactment, teacher-written case reports, and videotapes of teacher professional development worksessions—provided additional data to corroborate and enrich the story told by the case. For the purposes of this paper, telling" mini-cases related to investigation were excerpted from the nine lessons to weave the story of the case.

The nine lessons were selected prior to analysis; criteria for selection included (a) the central role of each lesson in developing the substantial science content of the project; (b) the opportunities that each lesson provided to explore key aspects of project-based instruction—and in particular, investigation and real-world decision-making; and (c) the extent to which activities were parallel across projects, which enabled comparing/contrasting instructional conversations (Tharp & Gallimore, 1988) for different activities within one project and for similar activities across both projects.

A theoretical model of shared sense-making grounded in the tenets of sociocultural theory was developed to provide a coherent theoretical framework for examining changing teacher-student interactions over extended time in an inquiry-based science classroom (see following section "Developing the Theoretical Framework"). Methods of conversation analysis (Psathas, 1995) and an analytical framework derived from the theoretical framework were used to characterize teacher-student interactions in terms of the following constructs of shared sense-making: (a) *joint attentional field*—on what object was joint attention focused and by whom; (b) *referential field*—what ideas/links were added to the referential field and by whom; (c) *perspectival shifts*—what shifts in perspective were initiated and by whom, and what corroborating or conflicting ideas/experiences were added to the referential field as a result of the shift; (d) *inquiry and reflection*—what coherence processes were carried out and who initiated/participated in those processes; and (e) *cohesive tools*—what cohesive elements were added to the referential field and by whom.

Research Questions

The following questions guided the theory development and the development of the interpretative case study:

- *The theoretical question:*

  What elaborations on sociocultural theory are necessary to provide the foundation for a systematic examination of shared sense-making within the naturalistic context of a middle-school science classroom over extended time?

  In particular, what role (if any) do inquiry and reflection play in a sociocultural model of shared sense-making?

- *The empirical question:*

  In what ways did Connie and her students' shared sense-making change over the course of a year-long scaffolded introduction to inquiry-based science instruction?

  In particular, in what ways did opportunities to engage in inquiry and reflection change over the course of the year?

Developing the Theoretical Framework

We explore the rich intersection of the literatures of inquiry, reflection, socioculturalism, and theory of mind to develop a sociocultural model of shared sense-making that permits exploring the role of inquiry and reflection in teacher-student shared sense-making in the classroom.

Foundational Vision of Inquiry/Reflection: The Writings of John Dewey

The writings of John Dewey provide the foundational ideas for much of current thinking in the areas of inquiry and reflection, including much of the last decade's work in project-based and inquiry-based instruction. Dewey did not differentiate between the terms inquiry and reflection, sometimes using the terms in combination ("reflective inquiry"), and sometimes interchangeably. Attempting to characterize this type of thinking—and distinguishing this thinking from other types—was a central unifying thread in Dewey's writings.

Characterizing the Constructs

In *How We Think*, Dewey (1910/1933) described reflection as a special kind of thinking that "consists of turning a subject over in the mind and giving it serious and consecutive consideration" (p. 3). He proposed that the function of such thinking was "to transform a situation in which there is experienced obscurity, doubt, conflict, disturbance of some sort, into a situation that is clear, coherent, settled, harmonious" (pp. 100-101). He further claimed that reflective thinking is differentiated from other types of thinking—such as stream of consciousness, imagination, unexamined belief—by certain characteristics., including (a) reflective thinking refers to a consecutive ordering of ideas, in which each idea derives from the preceding one and determines the next; (b) it leads toward a goal or conclusion; (c) it involves careful consideration of the evidence that supports a belief and the conclusions to which a belief leads; and (d) it involves both a state of "perplexity" that initiates reflective thinking and an act of searching to resolve the perplexity (Dewey, 1910/1933).

Dewey maintained that there is no need for reflection as long as activity is moving along smoothly; recognition of a fork-in-the-road, a dilemma, initiates a process of reflection:

> Thinking begins in what may fairly enough be called a *forked-road* situation, a situation that is ambiguous, that presents a dilemma, that proposes alternatives. As long as our activity glides smoothly along from one thing to another,…there is no call for reflection. Difficulty or obstruction in the way of reaching a belief brings us, however, to a pause. In the suspense of uncertainty, we metaphorically climb a tree; we try to find some standpoint from which we may survey additional facts and, getting a more commanding view of the situation, decide how the facts stand related to one another. (pp. 14, italics as in original text).

The outcome of inquiry was knowledge, or Dewey's term "warranted assertion" (p. 9), which could only be developed through a process of inquiry:

> Knowledge, as an abstract term, is a name for the product of competent inquiries. Apart from this relation, its meaning is so empty that any content or filling may be arbitrarily poured in. (p. 8)

Dewey conceived of inquiry as a continuous process, with the "settled belief" or knowledge that was the outcome of one inquiry providing the foundation for the next round of inquiry, but with that "settled belief" or knowledge always open to revision during subsequent inquiry.

Dewey (1938) claimed that experience is "felt" or "had" before it is known (p. 70-71; see also Taylor, 2002); that is, perception of a situation precedes understanding the relations that exist within it. According to Dewey, four types of relations exist that can be examined/developed through inquiry (Dewey, 1938; Kennedy, 1970, p. 74): *connection/involvement* (relations among existential things); *inference* (relations that connect the plane of existential things and their relations with the plane of symbol-meanings and their relations); *implication* (relations among symbol-meanings, resulting in abstract theories); and *reference* (relations connecting abstract theories to complexes of connections/involvements). Dewey conceived of inquiry as particularly concerned with exploring *referential* relations (Kennedy, 1970).

Thus, Dewey conceived of reflective thinking as an ordered sequence of thoughts directed toward a goal, arising from a state of doubt and involving an act of searching for possible means to resolve the doubt and for evidence to support those possible means. Reflective thinking provided a means of developing mental coherence in a situation of logical confusion or moral dilemma. This developing mental coherence—or "knowledge"—formed the foundation for the next round of inquiry, and was always open to revision during subsequent inquiry.

A Social/Cultural Process

Dewey viewed man as "a *social* animal," living within an environment that is culturally determined and acting in ways that are determined not only by biology but also by culture:

> Man, as Aristotle remarked, is a *social* animal. This fact introduces him into situations and originates problems and ways of solving them that have no precedent upon the organic biological level. For man is social in another sense than the bee and ant, since his activities are encompassed in an environment that is culturally transmitted, so that what man does and how he acts, is determined not by organic structure and physical heredity alone but by the influence of cultural heredity, embedded in traditions, institutions, customs and the purposes and beliefs they both carry and inspire. (Dewey, 1938, p. 43, italic emphasis as in original text)

Dewey described inquiry as being socially/culturally conditioned, because of its reliance on a culturally mediated symbol system and also because inquiry originates within a particular problematic situation in cultural context and results in modification of that situation in cultural context.

Dewey considered language to have a special function, as the cultural institution by which other cultural institutions are "transmitted" (p. 45). He defined language very broadly to include not only oral and written speech, but also gestures, ceremonies, and physical tools. Dewey also claimed that the existence/transmission of cultural activities is made possible through an individual's *taking the perspective of another* in the course of using language to communicate:

> …on the one hand, it [language] is a strictly biological mode of behavior, emerging in natural continuity from earlier organic activities, while, on the other hand, *it compels one individual to take the standpoint of other individuals and to see and inquire from a standpoint that is not strictly personal but is common to them as participants or "parties" in a conjoint undertaking*. (Dewey, 1938, p. 46, italic emphasis added)

Thus, Dewey conceived of inquiry as a systematic social and cultural process by which "warranted assertions" (knowledge) were continually refined through the resolution of particular problematic situations. He considered language to be a special broadly defined cultural institution that made possible the existence and transmission of other cultural institutions (with inquiry being one such cultural institution), *by enabling individuals to take on the perspective of another*.

Inquiry/Reflection: Synonymous or Mutually Constitutive?

Dewey considered one of the foundational problems of philosophy to be finding a way to integrate *logic* with *judgment*, to integrate an understanding of the world and its relations (and in particular understandings related to natural science) with an understanding of the values/goals that guide human decision-making (Hahn, 1970). Dewey proposed that such a unifying principle could be found in a common method applied to both logic and judgment—the proposed method was *inquiry* (Hahn, 1970):

> …the basic problem of present culture and associated living is that of effecting integration where division now exists. The problem cannot be solved apart from a unified logical method of attack and procedure. *The attainment of unified method means that the fundamental unity of the structure of inquiry in common sense and science be recognized, their difference being one in the problems with which they are directly concerned, not to their respective logics.* (Dewey, 1938, p.79)

Thus Dewey conceived of inquiry as a unifying process, a process of careful thinking capable of guiding development of a coherent body of scientific knowledge, and also capable of guiding thoughtful judgments during real-world decision-making.

However, it is not clear that defining a single unifying process, while maintaining traditional dichotomies in the domains in which it functions and in the outcomes that it yields, necessarily results in a unified whole.

Therefore, we suggest an extension of Dewey's proposal to unify logic and judgment through the method of inquiry, proposing instead that it may be more fruitful to consider achieving that unity through a mutually constitutive dialectic of two related processes—inquiry and reflection—with the special province of *inquiry* being exploring relations among perceptual experience and ideas (what Dewey termed inferential and referential relations), and with the special province of *reflection* being exploring relations among ideas (including memories, goals/intentions, and values/beliefs) (what Dewey termed implicatory relations). Consistent with the unity sought by Dewey, we propose that the mutually constitutive interaction of inquiry and reflection is equally relevant to scientific and everyday experiences, and to the world of objects and the world of agents.

Socioculturalism

Inherent in much of the research involving inquiry and reflection has been the assumption that such processes occur "inside the head" of an individual, and that co-construction of shared understanding occurs simply as a composite of individual sense-making processes.

However, the development of socioculturalism (Bruner, 1986, 1990; Palincsar, 1998; Rogoff, 1995, 1998; Vygotsky, 1987; Wertsch, 1985b) has contributed to a rather dramatic shift in conceptions of shared understanding and of the processes by which it is co-constructed. Going far beyond simply situating the individual thinker in social context, socioculturalism conceives of human understanding as co-constructed within, between, and among people in meaningful interaction in sociocultural context, a process that is mediated by intellectual tools, which simultaneously shape and are shaped by the unfolding interactions.

Foundational Vision of Socioculturalism: The Writings of L.S. Vygotsky

Russian psychologist L.S. Vygotsky, considered one of the "founding fathers" of socioculturalism, attempted to develop a unified theory of psychology that was capable of resolving the traditional dichotomies between the individual and the social, with the explanatory power to address the full range of human development—phylogenic, sociocultural, ontogenetic (Wertsch, 1985b). Vygotsky's work explored the relationships between the sociocultural/ sociohistorical, social, and individual planes of development, and proposed physical and psychological tools (in particular, semiotic signs and other artifacts of human activity) as mediational bridges connecting these planes (Wertsch, 1985b). The basic tenets of sociocultural learning theory as proposed by Vygotsky (1978, 1987) and later elaborated by (Wertsch, 1985a, 1985b, 1990) and others (Bruner, 1985, 1987; Minick, 1987, 1989) include:

- *A genetic (developmental) method:*

  Vygotsky believed that development was the result of multiple interacting forces; the task of a unified psychology was to study the changing interrelationships among sociocultural, social, microgenetic, and ontogenetic processes *over time*, in order to develop coherent explanatory principles (Wertsch, 1985b). He proposed that *explanatory* principles were developed by studying a body "in movement" as it developed over time; *descriptive* observations were developed by studying the static result, or "product," of that development.

- *Semiotic mediation:*

  Vygotsky proposed an important role for physical and psychological tools, and in particular semiotic signs, in mediating between the sociocultural, the social, and the individual, that is, between the intermental and the intramental planes. Vygotsky further proposed *decontextualization of mediational means*—the process by which sign-meanings become more and more independent of the context in which the sign was first designated—as the central explanatory principle of development in the sociohistorical domain (Wertsch, 1985b):

- *Sociogenesis of mind:*

  Vygotsky proposed a central developmental role for social interaction in sociocultural context, claiming that higher psychological processes in the child appear first in interaction between people, and then within the child:

  > We could formulate the general genetic law of cultural development as follows: Any function in the child's cultural development appears twice, or on two planes. First it appears on the social plane, and then on the psychological plane. First it appears between people as an interpsychological category, and then within the child as an intrapsychological category. (Vygotsky, 1981, p.163)

Near the end of his lifetime, Vygotsky proposed a construct called the Zone of Proximal Development (ZPD), which attempted to integrate the three foundational tenets of his theory—genetic method, semiotic mediation/decontextualization of mediational means, and the interaction of intermental/intramental processes (Moll, 1990; Wertsch, 1985b). (See later section entitled "Systems of Shared Sense-Making: Extending the ZPD Construct.")

Empirical Studies of Teacher-Student Classroom Discourse

Over the last decade, a number of researchers have used a sociocultural framework based on the above tenets and various types of discourse or conversation analysis to examine empirically teacher-student interaction in the classroom. Although most of these studies have not explicitly identified the scope of their exploration as teacher-student shared sense-making (as contrasted with student learning or teacher enactment), these studies provide a foundation of rich images and detailed analyses of teacher-student classroom interactions upon which to build the current exploration of shared sense-making. Four studies, in particular, provide a rich empirical foundation for exploring teacher-student discourse in science and mathematics classrooms (Leinhardt & Steele, 2005; Palincsar, Brown, & Campione, 1993; Rosebery, Warren, & Conant, 1992; Wells, in press).

These articles, singly and together, contribute to a rich foundation for continuing theoretical and empirical exploration of shared sense-making in a classroom context. In particular, they cumulatively suggest the following key ideas: (a) instructional interactions can provide opportunities to help make both teacher and student thinking visible, and analytical frameworks used in empirical analyses can/should provide ways to meaningfully characterize interactions that help make thinking visible; (b) instructional interactions can provide opportunities for students to participate in progressively more responsible ways in the shared sense-making of the classroom, and analytical frameworks can/should provide ways to meaningfully characterize those developing progressively more responsible interactions; and (c) instructional interactions can provide opportunities for the mutually constitutive interaction of doing, thinking, and thinking about thinking, and analytical frameworks can/should provide ways to meaningfully characterize those developing interactions.

A Model of Shared Sense-Making

Building on the key ideas related to inquiry, reflection, and socioculturalism, and the empirical studies of teacher-student discourse explored in the preceding sections, we propose a dramatic shift in the theoretical models and "unit of analysis" used to examine teaching and learning in the classroom. We propose that conceptualizing teaching and learning as mutually constitutive processes within a model of shared sense-making provides a fruitful theoretical framework for interpreting classroom activity. We further suggest that focusing on teacher-student interaction as the "unit of analysis"—rather than teacher enactment or student learning alone—opens up novel and productive ways to characterize unfolding events in the classroom. We propose that using a model of shared sense-making and a unit of analysis of teacher-student interaction can support both researchers and practitioners in conceptualizing the many complex interactions of the classroom—teacher and learner, individual and social, activity and ideas—as a unified whole.

Shifting the unit of analysis to teacher-student interaction creates a theoretical "Interaction Space" that requires theoretical definition. How can this space be characterized, in order to construct theoretical and analytical tools that will enable productive exploration of shared sense-making interactions in the classroom?

*The Interaction Space (**I**-space)*

First, we propose characterizing sense-making interactions and their development in terms of their position and movement within the theoretical Interaction Space (**I**-space) (Figure 1). The **I**-space is an extension of the theoretical 2-dimensional intermental-intramental plane of developing understanding originally proposed by Vygotsky (1987) and also an extension of an *n*-dimensional space proposed by Harré (1984) to describe the development of psychosocial entities such as cognition and memory (two major axes: *realization* (individual⇔collective); *definition* (personal⇔social)).

We propose characterizing sense-making interactions in the **I**-space in terms of three dimensions that span the space (and in terms of the poles of those dimensions): *realization* (individual⇔collective); *definition* (personal⇔social), and *convergence/control* (open⇔closed). We propose that the *realization* dimension can be equivalently conceived as "interaction in the perceived world," and the *definition* dimension as "interaction in the world of ideas and semiotic signs/symbols representing those ideas." A possible fourth dimension *affect* is not addressed within the scope of the current research study.

We propose that development of shared understanding can be characterized as movement within the multi-dimensional **I**-space and those movements through the **I**-space can be described as shifts in perspective, or *perspectival shifts* (see the later section entitled "Perspectival Shifts"). Thus, understanding develops through perspectival shifts—either shifting among the major axes of the **I**-space (from realization/action to definition/ideas to convergence/control; that is, from doing to thinking to thinking about thinking), or shifting along any particular axis (shifting perspective from one sense-making system to another, or shifting control back and forth from multiple possibilities (open) to a single possibility (closed)).

A Network of Systems of Shared Sense-Making

The interaction space can also be characterized as an interconnected network of systems of shared sense-making. The following constructs have been extended or elaborated in order to develop a coherent model of a network of systems of shared sense-making: (a) the *ZPD* (Vygotsky, 1987); (b) *theory of mind* (Astington & Olson, 1995; Hatano, 2002, 2005; Hatano & Takahashi, 2005; Lagattuta & Wellman, 2001; Tomasello et al., 2005); (c) *joint attentional* and *referential fields* (Tomasello, 1999; Tomasello, Carpenter, Call, Behne, & Moll, 2005); (d) alternation of perspective (Dewey, 1938; Tomasello, 1999) or *perspectival shift*; (e) *coherence processes*, including *inquiry* (AAAS, 1990; Dewey, 1910/1933, 1938; NRC, 2000, 2007; Schwab, 1966) and *reflection* (Schön, 1983, 1987); and (f) *cohesive tools* (Halliday & Hasan, 1976). Figure 2 provides a schematic illustration of this model of an interconnected network of systems of shared sense-making.

Systems of Shared Sense-Making

Vygotsky's zone of proximal development (ZPD) has generally been conceived as the difference in knowledge/performance that is characteristic of an individual learner when supported by a more knowledgeable other compared with the individual's knowledge/performance when acting alone (Vygotsky, 1987). However, a number of researchers, based on careful examination of the original Russian texts in the context of Vygotsky's complete works, have concluded that Vygotsky intended a more central role for the concept of the ZPD in his theory of development:

> English-speaking scholars interpret the concept more narrowly than Vygotsky intended, robbing it of some of its potential for enabling us to understand the social genesis of human cognitive processes and the process of teaching and learning. (Griffin & Cole, 1984, p. 45)

Moll (1990) made a similar claim regarding the ZPD as a key theoretical construct in Vygotsky's work:

> [Within the last phase of his life], shortly preceding his death, Vygotsky proposed the concept of the zone of proximal development. Thus the zone must be thought of as more than a clever instructional heuristic; it is a key theoretical construct, capturing as it does the individual within the concrete social situation of learning and development. (pp. 3-4)

Moll further suggested that the concept of the ZPD represented an important transformation of the theory itself, *enabling Vygotsky to integrate social activity into his theory while retaining the importance of sign and tool mediation*.

A number of researchers have suggested extensions/elaborations of the ZPD construct. Rogoff and Wertsch (1984) proposed that Vygotsky's ZPD involves "the joint consciousness" or "intersubjectivity" of the participants (p. 5), thus expanding the notion of the ZPD as a shared learning space where the depth of potential learning is not simply a function of the "ability" or "readiness" of the learner, but is also strongly dependent upon the ability of both learner and more-knowledgeable-other to develop "joint consciousness" or "intersubjectivity." Brown (1992) and Brown and colleagues (1993) further proposed that learning within the ZPD is multi-directional, not simply flowing from teacher to student; classrooms contain multiple ZPDs; and ZPDs can include artifacts and tools, as well as people. Finally, Wells (1999) summarized and continued the elaboration of these ideas, suggesting a central, very broad, and still developing role for the ZPD in sociocultural theories of learning:

> Vygotsky's genetic theory of learning and development can provide a starting point for rethinking the principles on which education should be based. And in that rethinking, the concept of the zone of proximal development has a central role to play. For, far from being simply a new and better pedagogical method, the zpd offers an insightful and theoretically coherent way of thinking about the complex nature of the transformations that are involved in learning and of the multiple ways in which learning can be assisted. (p 334)

Building on the above ideas, we propose a further extension of the construct that is consistent with, though more general than, the extensions already proposed by others. We propose broadening the definition of the construct to a human system of shared sense-making—a flexible association of humans, tools, and their interactions that enables shared sense-making. A human system of shared sense-making includes: (a) a particular set of participants and their interactions; (b) currently developed, and not-yet developed, interconnections among ideas of participants (*intellectual tools*), including the activity and participation structures that define the context for interaction; (c) physical representations of those ideas in the perceptual world that facilitate developing the ideas (*artifacts*), including those representations that facilitate modifying physical entities in the perceptual world (*physical tools*); (d) currently developed, and not-yet developed, interconnections with adjacent sense-making systems; and (e) the *potential* for developing shared ideas that arises from interaction of elements *a* through *d* (the *depth* of the sense-making system). Such a sense-making system evolves over time, changing as the elements change, which in turn alters the potential ideas (the depth) associated with the system. A sense-making system can include from many participants to a limit of one—the "solo" cognizing individual, now fully embedded in sociocultural and sociohistorical context.

We propose that systems of shared sense-making are an appropriate unit of analysis for examining teacher-student interactions in the classroom. To examine processes of shared sense-making within/among systems of shared sense-making, some additional constructs are needed.

Theory of Mind

"Theory of mind" has historically been defined rather narrowly by developmental psychologists as a single capability of mental representation that a child is judged to have attained or not attained at approximately 4 years of age depending upon a pass or fail score on a false-belief test. However, some developmental researchers (Astington & Olson, 1995; Bruner, 1995; Feldman, 1995; Lagattuta & Wellman, 2001; Leadbeater & Raver, 1995; Lillard, 1998) have recently proposed defining the construct more broadly as a complex understanding of the mediating role of mind between perceptions and actions, an understanding that a child develops throughout early childhood and that is itself mediated by perhaps multiple interacting biological and cultural factors.
Hatano (2002, 2005) claimed that "theory of mind" is an important missing element in much sociocultural research and that "complex forms of communication *such as negotiation of meaning*s are possible only when both speakers and listeners can effectively mentalize" (2005, p. 155, italic emphasis added); that is, when both speakers and listeners can conceive of other humans as having mental lives similar to (and different from) their own.

Tomasello (1999) attempted to integrate evidence from evolutionary and comparative human and primate developmental biology to elaborate a sociocultural theoretical framework. He proposed *intentionality/mentality*—the capability for humans *to conceive of other humans as having intentional/mental lives like themselves, that is, the capacity of humans to conceptualize "theory of mind"*—as the processes of social cognition that make human cognition unique among the species. Tomasello and colleagues (2005) added to these earlier ideas by proposing two parallel developmental trajectories: (a) a developmental trajectory of individual mental representations that culminates in the individual acting as an "intentional agent," that is, engaging in goal-directed action with conscious awareness of the goal; and (b) a developmental trajectory of social interaction that culminates in "shared intentionality" when intentional agents interact socially, that is, when participants consciously share goals and coordinate actions to achieve those goals.

Developing from this foundation of ideas, we propose defining theory of mind in its broadest sense as an individual's developing understanding/flexible control of the mediating role of (individual and collective) mind between (individual and shared) perceptions and (individual and coordinated) actions. We further propose that developing the understanding of oneself and others as "shared intentional agents" is not a developmental attainment of early childhood, but rather a complex set of understandings that mediates shared sense-making and is itself mediated by shared sense-making throughout an individual's life history.

Joint Attentional and Referential Fields

Tomasello (1999) proposed that shared understanding develops through the co-construction of joint attentional and shared referential fields. The joint attentional field refers to those elements of the perceptual field on which interacting individuals agree to focus their attention. The shared referential field refers to mental representations of the symbols/semiotic signs that individuals agree to use to designate elements/relationships in the joint attentional field. Tomasello and colleagues (2005) revised Tomasello's

(1999) earlier concept of shared referential field, instead proposing two referential fields—an individual's referential field and an individual's model of a collaborator's referential field.

We propose several elaborations of Tomasello's ideas, in order to advance the exploration of shared sense-making of the current study. First, we propose that the joint attentional and referential fields are mutually constitutive, rather than distinct, constructs. That is, we propose that not only does the joint attentional field provide perceptual images that influence what symbolic representations are created in the referential field, but also the symbolic representations that already exist in the referential field influence how the perceptual images of the joint attentional field are interpreted. We further propose making explicit the idea, not explicitly stated by Tomasello, that the joint attentional and referential fields represent conceptual elements of the mind, not physiological elements of the brain.

Tomasello's ideas lead to several very important inferences, which have important implications for the current exploration of shared sense-making. Tomasello's differentiation of the attentional field from the symbolic field that describes and interprets it is an important theoretical contribution, enabling his model to represent the important distinction in shared sense-making interactions between attending to the same perceptual images and coordinating thought to construct a bridge of convergent symbols/semiotic signs to mediate between shared perception and coordinated action. Perhaps of even greater significance, the separation of these two fields enables the attentional field to "attend to" the referential field; that is, the separation of these two fields enables the attentional field to focus on the contents of the referential field as an object of attention, that is, for the world of ideas and the unfolding "narrative experience" of constructing ideas to become objects of attention.

Of equally great significance is Tomasello's reconceptualization of the "shared referential field" as two separate fields within the mind of an individual—the individual's own referential field and the individual's model of a collaborator's referential field. It is a relatively straightforward extrapolation to propose that an individual can store experiences related to all the sense-making systems with which she interacts and can develop ideas about patterns within those experiences (i.e. can develop "theories of mind" for all the sense-making systems with which she interacts). It is another relatively straightforward extrapolation to propose that the processes of constructing a model of one's own mind from one's own mental/perceptual experiences and constructing models of other minds based on perceptual experiences and inferences of the mental experiences of those other systems are mutually constitutive processes, with each process using the other as a template. Finally, based on a similar line of argument, we propose that interactions within the real-world systems—that is, interactions within the flexible associations of humans that enable shared sense-making—are mutually constitutive with participants' mental models of those systems.

Perspectival Shifts

According to Tomasello (1999), learning to use linguistic symbols and other symbolic artifacts "transforms the way children view the world," providing simultaneously a sense of both the *intersubjective* (shared) as well as the *perspectival* (particular):

> The symbolic representations that children learn in their social interactions with other persons are special because they are (a) *intersubjective, in the sense that a symbol is socially "shared" with other persons*; and (b) *perspectival, in the sense that each symbol picks out a particular way of viewing some phenomenon.* (pp. 95, italic emphasis added)

The idea that an individual's mind includes implicit and explicit "models of minds" provides for the *contextualization* of images of experience/ideas within a particular mental model associated with a particular sense-making system. It also provides for the possibility of "perspectival shifts," *shifts in the relative proximities of images/ideas*, that enable images/ideas to be shifted (that is, *decontextualized*) from the context in which they were first encountered so that they can be used as a template for idea construction in other contexts. Thus, for example, images/ideas originally connected only to other images/ideas within an individual's mental model of the classroom sense-making system can, through a perspectival shift, be brought into closer proximity with images/ideas within the individual's model of her family sense-making system.

We propose that major perspectival shifts can be characterized in terms of the dimensions of the **I**-space, as discussed above.

Inquiry and Reflection: Mutually constitutive coherence processes

Building on the above foundation of theory development, and in particular, on the exploration of the constructs of inquiry and reflection, we define coherence processes as the synthetic and/or analytic pattern-matching processes that enable developing more tightly interconnected links within/among sense-making systems and mental models of those systems. Coherence processes include (a) *exploration* processes, through which sense-making systems "open" to consider multiple possible connections among actions/ideas and then "close" to a single "best fit" option based on culturally developed criteria of "best fit"; and (b) *dissemination* (or "ratcheting" (Tomasello, Kruger, & Ratner, 1993)) processes, through which "closed" actions/ideas are propagated based on culturally developed criteria of authority. Exploration processes, which foster movement in the **I**-space along the "open"/"closed" continuum of the convergence/control axis, have special significance because of their central role in flexible shared sense-making. We suggest further study of the role of affective weights in coherence processes, and in particular, in determining in which situations exploration or dissemination processes will be invoked.

We propose defining inquiry and reflection as two mutually constitutive exploration processes, through which humans *systematically* "open" to consider multiple possible interconnections among actions/ideas and then "close" to a single "best fit" option based on culturally developed criteria of reliability, such as consistency, repeatability, fruitfulness, and/or robustness; this "best fit" option then serves as a foundation for further idea development/action. (See later sections "Inquiry" and "Reflection" to compare/contrast these two mutually constitutive processes.)

We further suggest that perspectival shifts play a key role in inquiry and reflection. We propose that perspectival shifts involve consecutive shifts in relations within/among sense-making systems and mental models of those systems (along or across any of the axes of the **I**-space)—temporarily increasing the local incoherence of the sense-making network, but providing the opportunity for increasing global coherence through the recognition of new possible patterns as a result of the shifts in relations. We propose that systematic perspectival shifts drive the back-and-forth movement along the "open"/"closed" continuum of the convergence/control axis that is characteristic of the exploration processes of inquiry and reflection.

Inquiry. Inquiry can be described as the systematic, *data*-based exploration process that explores possible interconnections (static relationships/causal connections/interactions) among perceptual objects/events in the joint attentional field and signs/symbols in the referential field, based on systematic observation/measurement of objects/events in the joint attentional field (empirical data). Inquiry includes both the systematic use of perspectival shifts that supports opening to consider multiple possibilities, and the systematic evaluation of possibilities that supports closing to the most coherent/fruitful of the possibilities for a particular situation.

Reflection. Reflection can be described as a systematic, *logic*-based exploration process that explores possible syntheses of more complex from less complex ideas or possible analyses of less complex from more complex ideas within the referential field, based on comparisons with patterns of ideas already in the referential field. Reflection includes both the systematic use of perspectival shifts to open to consider multiple possibilities, and the systematic evaluation of possibilities that supports closing to the most coherent/fruitful of the possibilities for a particular situation.

In particular, reflection enables the construction of possible ideas such as conclusions or intentions to act (or predictions of others' intentions to act) from existing ideas such as theories, memories of prior experience, values and beliefs, and goals. Reflection also enables the reverse process—reconstructing the possible paths by which existing ideas or intentions to act may have developed. Reflection also includes the systematic integration of ideas and the processes for thinking about those ideas—that is, the mutually constitutive interaction of thinking and thinking about thinking.

Note that systematic perspectival shifts to open to consider multiple possibilities and systematic evaluation to close to a "best-fit" option are requirements for a process to be considered an exploration process, and therefore are requirements for a process to be considered inquiry or reflection.

Cohesive Tools

Finally, we explore semiotic mediation as the means by which thinking is made visible and shared within/among sense-making systems and models of those systems—and therefore, perhaps also the means by which interactions within/among sense-making systems and models of those systems can be examined empirically.

Halliday & Hasan (1976) define a text as any passage, spoken or written, that forms a unified whole and define the concept of "texture" to refer to the property of "being a text." They then examine various literary tools that function to create texture within a spoken or written passage.

We propose defining the notion of text, consistent with but perhaps even more broadly defined than current broad definitions of text in the field of literacy, to include any unfolding sequence of human interactions that form a unified whole (which can also be termed "narrative experience"). We further propose that a sequence of interconnected referential fields that serve to interpret that unfolding narrative experience is also a text, and various types of intellectual tools function (and can be constructed to function) to create cohesion of various sorts within that narrative experience (see also Wells, 1999, for a different proposed synthesis of Vygotsky's and Halliday's ideas).

Case Study: Exploring Shared Sense-Making in a Project-Based Science Classroom

The theoretical/analytical tools developed in the preceding sections provide a framework of shared sense-making for interpreting Connie and her students' interactions over the course of a year of scaffolded introduction to project-based science instruction.

"Telling" Mini-Cases: Developing Ideas through Investigation

Through "telling" mini-cases we explore Connie and her students' developing shared sense-making as they engaged in three long-term experiments/investigations over the course of a year of instructional interactions. The experiments/investigations included (a) a long-term prescribed experiment ("Grass Seed Experiment") carried out during Fall, Year 1, during the *What's in Our Water?* unit; (b) a long-term prescribed experiment ("Effects of Acid Rain on Non-Living Things") carried out during Spring, Year 1, during the *Acid Rain* unit; and (c) a culminating end-of-year long-term investigation ("Effects of Acid Rain on Living Things"), in which students designed their own investigation.

Making Sense of a Long-Term Prescribed Experiment (Grass Seed Experiment)

Connie and her students' first major activity, a long-term prescribed experiment entitled the "Grass Seed Experiment," explored two interrelated questions—(a) what is the relationship between nitrate treatment level and grass growth/health (nitrate as a fertilizer); and (b) what is the relationship between nitrate treatment level and concentration of nitrate that percolates through the soil as a result of "leaching" (nitrate as a potential pollutant of the ground water). The activity involved small groups of 2- 3 students treating three small cups of sand and grass seed with No, Low, or High Fertilizer treatment solutions and observing the results over a two-week period. The experiment included three parts: (a) Part I, to set up the treatment cups; (b) Part II, a partial lesson one week after set up of the treatment cups, to make intermediate measurements of grass growth/health; and (c) Part III, to make final measurements of grass growth/health, measure the concentration of nitrate that “leached” through the sand, and make sense of the results.

Connie structured the first lesson (Part I) as a fairly typical hands-on activity in three segments: (a) a whole-group, mainly lecture-demonstration segment to introduce the activity and rehearse prescribed procedures; (b) a small-group hands-on activity segment during which students worked independently to set up their treatment cups; and (c) a whole-group recitation segment to make sense of the activity. Connie decided to demonstrate proper procedures during the introductory segment of the lesson and then allow students to work independently to set-up their own treatment cups during the small group segment, in order to scaffold correct lab procedures while also enabling students to act more independently than if she had led the whole group step-by-step through the complete experimental set-up (CH, Clip Interview #1). She further decided to defer sense-making of the activity until after they had completed the experimental set-up, to ensure that they would have time to complete the set-up during their single 45-minute class period (CH, Clip Interview #1).

Rehearsing procedures for setting up a prescribed experiment. The introductory segment of the lesson was a fairly traditional well-executed lecture-demonstration rehearsing procedures for setting up a prescribed experiment. Connie demonstrated step-by-step the prescribed procedures that her students would need to follow to set up the experiment. As she demonstrated procedures, Connie also gave verbal instructions to highlight important aspects of each step. Teacher moves such as using hand gestures or hand gestures with experimental materials to demonstrate experimental procedures, walking around the classroom making eye contact with each student as she assigned treatment conditions, incorporating a particular small group into her whole-class demonstration of correct labeling of treatment cups—seem to be doing the intellectual work of making bids to establish joint attentional fields. Student nonverbal responses suggest that many students were responding to the teacher bids and were attending to the joint attentional fields proposed by the teacher. Connie’s step-by-step verbal instructions seem to be doing the work of elaborating a referential field highlighting salient features of the teacher-proposed joint attentional field.

Connie decided to limit student participation during this introductory segment of their first major long-term experiment because of her strong awareness of important time constraints and management issues (CH, Clip Interview #1). Connie facilitated only one opportunity for student participation during this introductory segment:

T: Why put holes in the cup?”

S: <To let the water out.>

T: [Nodding] <Inaudible brief acknowledgment>

(Grass Seed Exp, Part I: Seg 00:03:58–00:04:39)

In this single instance of student participation, Connie chose to focus on a step that she considered to be less significant in terms of substantive content, in order to ensure that her initial invitations to participate were well within the knowledge base of all of her students and therefore would foster broad student participation (CH, Clip Interview #1, Reflections Interview, personal communication). Interestingly, however, Connie's question was not answerable from the stream of narrative images and descriptions associated with each student's model of the classroom referential field, as most "recitation"-type questions are. Thus, Connie's question required students to shift from the stream of narrative images and description associated with students' model of the classroom referential field to their model of their own referential field (a perspectival shift from social⇔personal definition/ideas) in order to respond to the question.

Note that there were many possible student responses to this simple Why question, from the simple explanation of intended purpose that was provided, to more complex conceptual explanations of the causal relationship between soil moisture and mold growth or between oxygen in soil air spaces and root respiration. Perhaps to maintain the pace of her first major activity (CH, Reflections Interview), perhaps to avoid any possibility of intimidating her first student respondent (CH, Clip Interview #1, Reflections Interview, personal communication), perhaps because she was content with the response that had been provided and with the student participation that had been successfully fostered, Connie acknowledged the single student response as correct and continued with her demonstration of experimental procedures.

During this introductory segment, Connie infrequently added a brief explanation to her description of a procedural step. That is, in terms of the theoretical/analytical frame of shared sense-making, she executed a perspectival shift from procedural description⇔theoretical explanation/interpretation, enriching the procedural description by linking it to a related causal chain and/or intended purpose. For example, as she provided instructions regarding how to spread the grass seed on top of the sand-filled cup, Connie added explanatory detail (a causal chain associated with the need to treat the seeds gently):

> *T:* […] And you're going to get <u>one</u> level teaspoon of grass seed and put it on top of your sand and very GENTLY spread it out—don't BANG on it, *because you'll damage the seeds and if you break them and damage them they won't grow.* So, do it very, very gently.
>
> (Grass Seed Exp, Part I: Seg 00:06:44–00:07:20, italic emphasis added)

And, as she demonstrated how to pour fertilizer over the seeds, Connie provided an intended purpose for carefully pouring the fertilizer:

> *T:* […] Very carefully pour it on top of the grass seed, kind of sprinkle it, don't dump it, pour it very carefully [tchr pretends to carefully pour fertilizer from beaker] *so that all the grass seed gets some fertilizer*.
>
> (Grass Seed Exp, Part I: Seg 00:07:52–00:08:55, italic emphasis added)

These occasional perspectival shifts from procedural description⇔theoretical explanation/interpretation added some depth (that is, another perspective) to the sequence of procedural images and description. However, these occasional associations of brief causal chains or intended purposes with a prescribed procedural step contrast both in detail and in scope with explanations that would have supported the procedural descriptions if teacher and students had themselves designed the experimental procedures. Of particular significance, the occasional explanations that Connie added provided conceptual explanation/interpretation at the level of the individual procedural step, not at the level of a broader framework of ideas such as "investigation" or "experimental design."

Setting up a prescribed experiment. During the small group segment, Connie circulated from group to group, taking the time to engage with each student around the task of correctly setting up their treatment cup. Described in the shared sense-making framework, Connie established a clearly engaging joint attentional field with each student that was focused on "their cup." The brief 2- to 20-second interactions scaffolded each student to execute a perspectival shift of collective⇔individual realization so they could set up their own treatment cup following the procedures that Connie had demonstrated to the whole group.

According to the theoretical frame, executing such perspectival shifts should result in the procedural images of Connie's demonstration that had been contextualized in students' model of the classroom referential field being shifted to images of their own enactment associated now both with their model of the classroom referential field and also with their model of their own referential field. Note, however, that these interactions show little evidence of perspectival shifts of social⇔personal definition/ideas. That is, there is little evidence in the transcripts that students wrestled with making sense of either the procedures or the experimental design as they imitated prescribed procedures to try to make their treatment cups look like Connie's; there is also little evidence that students considered alternative possibilities for setting up their cups. Rather, students simply asked for and received teacher acknowledgment that they were correctly following the prescribed procedures. However, the activity provided an opportunity for Connie to scaffold constructive student participation in developing images of their own enactment of experimental procedures—handling and sharing experimental equipment and materials, carefully labeling experimental treatments and following prescribed procedures, moving independently about the classroom—at a level that appeared to be accessible and engaging for a large majority of her students.

Making shared sense of a prescribed experiment: Nacent reflection. At the conclusion of the small group segment, approximately 4 minutes of the class period remained for Connie and her students to begin to make sense of the intellectual affordances of this key experiment. Connie's students—most of whom had never before had the opportunity to carry out an investigation, who had described an experiment as "mixing medicines together" during the first lesson introducing project-based instruction—now shared the common narrative experience of having set up their own treatment cups in the service of carrying out a classroom experiment. However, their instructional conversation up to this point had provided few tools to help students to make shared sense of the richly detailed images of this narrative experience—what were the important images in the hundreds of successive images in the procedural narrative to focus on and remember, what were the ideas that would link sequences of images together, what were the overarching ideas that would recur repeatedly as common elements in other experiments and investigations? No overarching ideas had yet been "seeded" in the classroom referential field that could later become the object of a social⇔personal definition/ideas perspectival shift to support shared sense-making. No action⇔ideas perspectival shifts had yet been orchestrated to scaffold students in finding patterns in their own experiences. Through their interactions over the next four minutes of the lesson and over the next four weeks of the project, how could Connie and her students use the affordances of these richly detailed shared procedural images to begin to make shared sense of the process of scientific investigation?

Connie divided the concluding whole-group recitation segment into two parts—making predictions for the No Fertilizer cups and making predictions for the Low/High Fertilizer cups. The two discourse sequences used almost identical, apparently open-ended, questions to solicit the prediction:

For the No Fertilizer cups:

T: ***So, what do you expect will happen to the cups that have just sand and grass seed?***

(Grass Seed Exp, Part I: Seg 00:030:21–00:31:21, italic/bold emphasis added)

For the Low/High Fertilizer cups:

T: ***Now, what about the high and the low fertilizer, what do you think's going to happen?***

(Grass Seed Exp, Part I: Seg 00:31:21–00:33:32, italic/bold emphasis added)

Such opportunities for prediction should provide opportunities for students to engage in reflection, as students are challenged to search through their existing ideas for possible causal/synergistic interactions that might be relevant to making predictions of possible outcomes in a particular situation. However, the two predictions were embedded in two very different discourse sequences that fostered very different intellectual work.

For the No Fertilizer discourse sequence, Connie's solicitation for a prediction was embedded in a longer discourse chain:

T:	All right, I just want to talk just for a few minutes about the experiment and *what we expect will happen.* Now, you've all probably been to the beach at one time, OK^. What do you see USUALLY growing in sand?
Ss:	[Calling out] Seaweed….Crabs….Nothing….
T:	OK, [tchr pointing to std who said "Nothing"] you're right, absolutely nothing. ***So, what do you expect will happen to the cups that have just sand and grass seed?***
S1:	[Std hand shoots up, tchr calls on her] Nothin' will grow in 'em.
T:	OK, first you need to know that there's a little bit of food inside the seed itself, so that the seed can get started, but what's going to happen after the seed gets started, if it's growing just in sand?[1] [*S2* raises hand; teacher motions to *S2*]
S2:	It won't have no place to plant its roots, like in the soil.
S1:	[*S1* joins in] It won't have nothin' to feed on.
T:	[Tchr nods in affirmation to *S1*'s response] OK.

(Grass Seed Exp, Part I: Seg 00:030:21–00:31:21, italic/bold emphasis added)

Note that the "So" that prefaced Connie's solicitation for a prediction refers back to the conclusion of a preceding set of turns in the discourse chain that Connie had constructed to lead students to an idea that she had in mind (and that she believed few of her students would already know)—that energy/nutrients stored in the seed might enable the grass in the No Fertilizer cups to sprout and initially grow (CH, Post-Instruction Interview #2, personal communication). Thus, a question that appeared to have the form of an open-ended question asking students to search their own minds for potential connections between possible causal/synergistic interactions and possible outcomes, when considered in the context of the discourse chain in which it was embedded, was actually part of a carefully constructed chain of closed moves designed to lead students to an idea that the teacher had in her own mind. Connie added important new information to the classroom referential field about nutrients/energy stored in the seed that she believed students would not know—and students seemed to enjoy trying to guess the idea that the teacher had in mind. However, the discourse chain led to a single closed idea that the teacher had in

[1]Note that Connie chose not to grapple in their first *What's in Our Water?* project with distinguishing between the scientific definitions of "food" (a source of chemical potential energy) and "nutrients" (a source of chemical compounds/chemical building blocks) for plants, a distinction that she thought was peripheral to the project and would be conceptually difficult for her students (CH, personal communication).

mind, rather than scaffolding students in doing the open-ended search for possibilities within their own minds—the perspectival shifts of closed⇔open control, social⇔personal definition/ideas, and theoretical explanation (ideas)⇔predicted outcome (action)—that characterizes the real intellectual work of a prediction.

In contrast, in the second discourse sequence, Connie did not set up a prior chain of analogic reasoning to scaffold (and constrain) student responses. Therefore, Connie's solicitation for a prediction was truly open-ended, challenging students to pull together their earlier procedural images from the experimental set-up and their own understandings about fertilizer and grass growth in order to make their own predictions:

T: ***Now, what about the high and the low fertilizer, what do you think's going to happen?*** *S3^*.

S3: <They're going to grow much easier>, the low [fertilizer] will grow easier than the high, the high might not grow *because it has too much fertilizer.*

T: OK, *S3* says that she thinks that the low fertilizer will grow the best because she thinks the high fertilizer might be TOO MUCH fertilizer and that might make it not grow very well. *Does anybody else have a different opinion?* We're just asking for *predictions. I'm not going to say whether anybody's right or wrong, cause we'll find out as we watch. S4^*.

S4: I think it would grow better UNDER the soil.

T: Grow better what?

S4: UNDER the soil.

T: Well, I'm going to put a little bit of soil on top of all of the grass seeds in the cup, just a little bit, like your dad does when he puts new grass seed down in your lawn, he always puts just a little bit of dirt, and I decided that I would do that so that it would all be an equal amount in all the cups, OK^. *S2^*.

S2: I think the no fertilizer will grow but not as good, like it will grow slower, but the low fertilizer will grow like almost normal, or the HIGH fertilizer will grow like almost normal grass [*T* [nodding]: OK] outside, when you put the soil on it, it'll grow almost like normal grass, and the low fertilizer might grow like half grass.

T: OK, let me ask you a question [first looking at *S2*, and then broadening her gaze to the whole class]. What does the fertilizer provide for the grass seed?

(Grass Seed Exp, Part I: Seg 00:31:21–00:33:32, italic/bold emphasis added)

In this case, students provided rather lengthy and detailed responses that were not already part of the chain of discourse associated with the classroom referential field. Thus, in the conceptual frame of this study, Connie's open-ended question had scaffolded students to engage in a perspectival shift of social⇔personal definition/ideas. Although not specifically solicited by the teacher's request for a predicted outcome, the first student respondent also provided the theoretical explanation that she had used to develop her prediction—a necessary element of a prediction in order for a student to make evident the chain of intellectual work involved in making the prediction. Connie continued to reinforce the open-ended nature of their exploration of possible predictions, as she acknowledged the student's response:

> *T:* OK, *S3* says that she thinks that the low fertilizer will grow the best because she thinks the high fertilizer might be TOO MUCH fertilizer and that might make it not grow very well.
>
> *Does anybody else have a different opinion?* We're just asking for *predictions. I'm not going to say whether anybody's right or wrong, cause we'll find out as we watch.*
>
> (Excerpted from main transcript above; italic emphasis added)

By the end of this discourse segment, students had had the opportunity to consider multiple possible explanations and outcomes for an experimental situation, as three different student predictions of grass growth in response to the Low and High Fertilizer treatments—and three different possible causal relationships leading to those outcomes—were added to the classroom discourse. Unfortunately the end of the class period cut short this discussion and did not permit the whole group to have the opportunity to complete the intellectual work of making a prediction—that is, to fully wrestle with understanding the relationship between the causal relationship between nitrate treatment and grass growth and the real-world predicted outcome (a perspectival shift of ideas⇔realization), and to decide for themselves which predicted outcome was most likely based on which of the multiple theoretical explanations seemed to them to be the most fruitful (perspectival shift of open⇔closed convergence/control).

It is of interest to examine these two parallel situations of classroom discourse to consider what might have led to the different sequences of discourse moves. In the first sequence, with three minutes of class time remaining, the teacher consistently used discourse moves that closed the conversation down toward predicting a single possible outcome; in the second sequence, with two minutes of class time remaining, the teacher consistently used discourse moves that opened up the conversation to consider multiple possible outcomes. Clearly time was not the deciding factor in these very different teacher decisions. Other possible interpretations can be found within Connie's interviews and informal conversations (CH, Post-Instruction Interview #1, Post-Instruction Interview #2, personal communication). Connie was fairly certain that she understood what would happen in the No Fertilizer cups. She thought that the No Fertilizer treatment would not sustain grass growth for an extended time, because the sand and the distilled water did not contain the essential nutrients required for plant growth; however, she also thought that the grass would grow initially for a brief time, because of the nutrients/energy stored in the seeds. She was concerned that many of her students would not have the background knowledge to know about the nutrients/energy stored in the seeds and therefore she believed that it was important to give them that background information so that they would not become confused by anomalous results as they observed their treatment cups over the extended two-week experiment. Thus, Connie's own referential field included only one possible prediction/explanation for what would happen in the No Fertilizer cups, once students understood the potential confounding effect of nutrients/energy stored in the seed. This one possible prediction/explanation was tightly interconnected with what Connie had identified as some of the important science content of the experiment (CH, Post-Instruction Interview #1, Clip Interview #1).

In contrast, Connie had been unable to locate (in November) fertilizer with the nitrogen/phosphorus/potassium ratios recommended in the experimental setup and had made her own non-standard Low and High Fertilizer treatment solutions (CH, Post-Instruction Interview #1, personal communication). Therefore, Connie was uncertain regarding whether the Low or the High Fertilizer treatment condition would grow better (CH, personal communication). Thus, Connie and her students were on an equal footing in this second half of the experiment—neither knew what "answer" to expect, both were engaging in an open-ended exploration (or inquiry) into what might happen to the growing grass by adding Low and High Fertilizer treatments. In this second discourse sequence, the referential fields that teacher and students co-constructed included multiple predictions that both teacher and students believed to be possible outcomes; and which prediction turned out to be correct did not alter the fundamental conceptual relationships that were illustrated by the experiment.

It is interesting to note that, in both sequences, Connie asked repeatedly *what* students expected would happen, but not *why* they thought that predicted outcome would occur—that is, she emphasized (and named) the idea of making a *prediction* regarding *what* outcome was mostly likely to occur, but not the idea of constructing a chain of possible theoretical relationships (an *explanation/interpretation*) to explain *why* the predicted outcome was the most likely. It is this latter search for possible relevant theoretical relationships, and which real-world outcome would indicate which theoretical relationship was actually operating in a particular situation, that is at the heart of the reflective intellectual work of making a prediction. It is unclear how (i) substantial time constraints during the conclusion of this first major experiment, (ii) the desire to find supportive and inclusive ways to scaffold initial student participation, and/or (iii) a possible assumption that "correct" predictions demonstrated "correct" underlying conceptual understandings played into Connie's decision not to probe more the theoretical rationale motivating students' predictions during this initial lesson.

Constructing a basis for shared sense-making. The first lesson of the Grass Seed Experiment afforded a number of opportunities for Connie and her students to engage in substantive shared intellectual work. For students who had little or no prior experience with scientific investigation, the sequence of rich procedural images that resulted from engaging in setting up their own treatment cups provided students with an important foundation upon which to build later conceptual work. Connie and her students had begun to engage in the important intellectual work of co- constructing predictions—important nascent opportunities for Connie and her students to begin to participate in the process of reflection. In the process of constructing those predictions, they had begun to explore interrelationships among some important scientific ideas, including nutrient levels in sand and distilled water, energy/nutrients stored in seeds, and the possible effect of various concentrations of fertilizer on growing plants. Thus, Connie and her students had taken some important first steps in developing tools that would help them to make shared sense of the results of this particular activity, a reasonable goal for the first day of their first major hands-on exploration. They had also participated in a set of experiences, not yet specifically named, that had challenged them to begin to reflect.

However, at the conclusion of this first lesson, Connie and her students had not yet added to the referential field ideas that would help them make shared sense of open-ended inquiry/reflection—where do the questions come from that drive scientific investigation, what are some of the important considerations that guide designing an investigation, what determines the steps of an experimental procedure, what data is gathered and why, what are legitimate conclusions to draw from empirical evidence and why. As we explore the remaining lessons in this two-week experiment, and in Connie and her students' two six-week projects, it remains to be seen to what extent the sequence of teacher-student interactions in this introductory lesson defined the beginning of a developmental trajectory that would enable Connie and her students' instructional conversation to move into this very important conceptual terrain.

Making Sense of a Long-Term Prescribed Experiment (Effects of Acid Rain on Non-Living Things)

We rejoin Connie and her students' instructional conversation during their second project of the year, another National Geographic Kids Network unit entitled *Acid Rain* (National Geographic Kids Network, 1989). The unit explored the causes and effects of acid rain as students designed their own rain collectors and collected real-world data to answer the question,"Does acid rain fall on my community?"

As we rejoin their conversation approximately three weeks after the start of the unit, Connie and her students are engaging in the initial set-up of a long-term prescribed experiment to explore the effects of acid rain on non-living things. The experimental design involved groups of four students placing samples of a particular test substance in clear plastic cups that were filled with one of three treatment solutions (distilled water to serve as a control, a solution of diluted vinegar representing acid rain, and a solution of full-strength vinegar representing a more concentrated acid than acid rain). Connie provided eight different substances to test (brick, asphalt, steel paperclips, copper pennies, rubberbands, plastic buttons, shells, and chalk), representing different materials found in the environment.

The first lesson of the Effects of Acid Rain on Non-Living Things experiment was structured very much as Connie had structured the introductory lesson of the Grass Seed experiment—(a) an introductory whole group lecture-demonstration segment to introduce the activity and rehearse prescribed procedures; (b) a small-group hands-on activity segment during which students worked independently to set up their treatment cups; and (c) a concluding whole group lecture-recitation segment to make shared sense of the activity. Similar to Grass Seed Experiment Part I, Connie again planned the activity so that shared sense-making would take place at the end of the lesson, after the procedural set-up of the activity had been completed.

Defining what to observe: Nascent reflection. The introductory segment of the lesson was brief. The set-up of the activity included many elements already familiar to students—labels were similar to those used in the grass seed experiment; pH strips had been used to measure acidity in several earlier activities during this unit; observations had been recorded for several different short-term and long-term experiments over the course of two projects. In addition, more than 10 minutes of the class period had already been taken up with a preview of an activity that students were to do in the science computer lab the following day. Therefore, Connie provided only a brief overview of the rather straightforward experimental procedures so that students could quickly move on to setting up their treatment cups, in order to allow time at the end of the activity to discuss what the various substances represented in the environment. Connie quickly summarized the kinds of observations that groups should make on their "mystery" substance and explained why their initial observations were fundamental to their sense-making of the final results:

> *T:* After you've done that, you're going to take out and open up your 'Mystery Envelope.' In your mystery envelope you'll find three things that are alike, and *you're to write down your observation—you look at it, you feel it, is it hard, is it soft, is it shiny, is it round, is it flat, is it white? You want to give a full description. Does it have any kind of a smell?*
>
> *Because we're going to put it in chemicals and it may or it may not change. And the only way you're going to know if it's changing is if you look at your description and compare it as it changes.*
>
> (Effect of Acid Rain on Non-Living Things: Seg 00:15:21 – 00:18:49, italic emphasis added)

However, Connie did not provide students with a rationale regarding why some observations might be more fruitful to make than others. That is, she did not orchestrate a perspectival shift from realization⇔ideas to seed ideas regarding the relationship between the possible effects of acids on substances and the pre- and post-observations that might be fruitful to make in order to detect those possible effects.

During the small group segment, the groups easily completed labeling their three cups, filling the cups with one of the three treatment solutions, and measuring the pH of the solutions. However, they struggled with how appropriately to describe their substance. Not understanding how the substances might change as a result of their exposure to "acid rain" and not understanding that their observations would be their means to determine whether their substances had or had not changed during the experiment, students struggled with what observations they should make to describe their very different substances. Many students thought that simply naming the substance was sufficient; one student thought that a worthwhile observation to help him explore the effects of acid rain on his penny was the date that his penny was minted:

T: […] Do you have all the pH's recorded? All right, now you can open up your mystery items and make a full description of what your mystery item is.

S1: 1977 penny.

T: Well, you want to describe them, what would you say about this penny?

S1: Uh, wellll…

T: Made out of?

S2: Made out of copper.

S4: Drop it in?

T: [Shaking her head] DESCRIBE it first.

(Effects of Acid Rain on Non-Living Things, Part I: Seg 00:20:00 – 00:31:35)

Although the experimental procedures themselves were rather straightforward, Connie had insufficient time to spend with each small group during the small group segment to help each group develop within its own referential field these rather sophisticated ideas about observation that had not already been seeded in some form in any of the referential fields associated with the whole group, small groups, or individual students.

Making shared sense of a prescribed experiment. At the end of the small group work, the class came back together as a whole group to find out what the different "mystery" substances were that each group was testing and to discuss what those substances represented in the environment:

T: Now, what I want to do before we put them over there is I want everybody to find out what the different substances are, OK^. Substance for Group #7 [pointing to group 7], what did you have?

S1 (group 7): A penny.

T: OK, what might a penny represent out in the environment?

Ss in group: Copper…. Metal… [tchr with hands open encouraging more response] Statues…

T: OK, I heard it from you [motioning to std in group]. Statues. It might represent statues, such as the Statue of Liberty or other statues that stand, that stand out in the rain. All right, group #8 [tchr pointing to group], what did you have?"

S2 (group 8): Shells.

T: OK, shells. Why would we care about shells, why might we want to test shells? Who are shells, what are shells important for?

S2: They're in the ocean?

T: OK, they're in the ocean, but why? [pause] What's inside a shell?

Ss in class: [Calling out] An animal… Some kind of animal… [tchr leaning to hear stds quiet comments]

T: Some kind of an animal. And what does the shell do for that animal?

Ss in class: [Calling out] Protects it.

T: It protects it, gives it a place to hide, gives it a home. If something happens to that shell, what's going to happen to that animal inside?

S in class: [Calling out] It dies.

T: OK, so let's pretend like those are snail shells [motioning to group 8]. I didn't have any, those are ocean shells, but let's pretend they are snail shells, we might find snails in a local lake or a stream or something, and if acid rain gets into that stream, it acidifies that stream, and let's see what's going to happen to those shells.

(Effects of Acid Rain on Non-Living Things, Part I: Seg 00:20:00 – 00:31:35)

Making sense of an experimental set-up *after* completing the set-up of the experiment had profound implications regarding the kinds of ideas that Connie and her students could develop from the experiment. As the second major long-term investigation of the year, based on a prescribed experimental design very similar to that of the Grass Seed Experiment, the activity provided many affordances for beginning to explore some of the central ideas associated with investigation—what questions drive an investigation, what experimental treatments should be used and why, what observations/ measurements should be collected and why, what are appropriate ways to represent data to facilitate sense-making, what are appropriate conclusions to draw from the data collected. However, whether such questions are explored at all, and if explored, whether such questions are explored *before* or *after* an investigation has been set up, creates an instructional conversation that does very different intellectual work. What purposes were served in Connie and her students' instructional conversation by making sense of these two long-term investigations *after the investigations had been set up*, rather than *before the investigations began, as a scientist would*?

Connie and her students' orchestrations of the Grass Seed and Effects of Acid Rain on Non-Living Things experiments had the potential to perform several seemingly different functions in their instructional conversation—allow Connie and her students to participate in: (a) a real-world demonstration of key scientific ideas related to the unit; (b) a real-world demonstration of the process of investigation; or (c) the intellectual work of actually carrying out an investigation. Framing a situation from the *closed* perspective of demonstrating key ideas and known relationships (as in (a) and (b) above), and framing a situation from the *open* perspective of inquiring into ideas that might be relevant to making sense of unknown relationships (as in (c) above), are both important, but very different, intellectual functions in the scientific enterprise.

How was the Effects of Acid Rain on Non-Living Things experiment being used as a template of experiences to shape ideas? It could have been used by Connie and her students (as it was) to develop images of important scientific ideas, such as acids and bases, and the impact of acid rain on everyday materials. Or, it could also have been used (as it was implicitly, if not explicitly) as an example investigation, providing concrete images of the scientific processes of measuring, making observations, and analyzing data in a controlled situation with a known outcome. Or, the experiment could have been used to support the process of reflecting on/inquiring into important questions (with unknown answers) that students might have about the effect of acid rain on their own environment, with the prescribed experiment simply providing one of many possible templates of experimental designs to guide that exploration. In the first two "closed" cases, the activity provides demonstrations of important scientific ideas, which were themselves at one point the objects of inquiry/reflection, but which are now being taught as the current best explanation for the phenomena under study. In the third "open" case, the experiment provides an entrée into the experience of engaging in inquiry/reflection—an opportunity to engage in perspectival shifts of closed⇔open control to explore possible ways to derive ideas from real-world observations and possible ways to interpret real-world phenomena using ideas. Although all three are legitimate parts of an instructional conversation about inquiry-based science, it seems important for teacher and students to understand which role a particular activity is playing in advancing their conversation. It is important to clearly distinguish between the two, so that students do not mistake a "closed" demonstration of nitrate leaching or acid-base chemistry for the "open" inquiry/reflection that forms the fundamental basis for scientific exploration. Whether one makes sense of an experimental set-up before or after one completes the set up, and whether procedures are "followed" or "questioned," provide important clues regarding what intellectual work a particular instructional conversation may be doing and where along the open⇔closed continuum of the control axis it may reside.

Making Sense of Experimental Design (Effects of Acid Rain on Living Things)

The last major long-term investigation of Connie and her students' instructional conversation was also a pedagogical investigation—to discover if Connie and her students' instructional conversation had developed to the point that it could scaffold designing and orchestrating their own investigation. Connie made several decisions to keep the activity manageable—(a) she and her students would begin the activity after students had taken their unit test, thus eliminating time constraints imposed by a tight unit timetable; (b) Connie would pre-select the general area of inquiry, in order to contain the content explored and the materials required; and (c) Connie would pre-select the test organism, in order to contain the cost, confusion, and effort of assembling a large variety of materials (CH, personal communication). Connie decided that the area of inquiry would be to explore the effects of acid rain on living things (a design activity that she had already had some experience with herself during an earlier professional development activity and that would follow on nicely from her students' earlier prescribed experiment testing the effects of acid rain on non-living things). She decided that the test organism would be bean seeds, which would be easy and inexpensive to grow. She further decided that the experiment would be designed as a whole group experiment, with each study-buddy pair setting up one cup, in order to keep the number of treatment cups on her windowsill to a manageable quantity.

Although such a "whole-group" design approach would make it somewhat more difficult for students to conceptualize the experimental design as an integrated whole, it is interesting to consider this approach to design in terms of the "dance" in Connie and her students' instructional conversation between developing small-group and whole-group referential fields. Such a whole-group design would enable each small group to begin to wrestle with the question of how to design an experiment, but did not require that all small groups actually solve the design problem on their own. Rather, the small groups could bring partial ideas developed in the small-group referential fields back to the whole group, and those ideas could contribute to constructing a single shared design within the whole-class referential field. Since each study-buddy pair would set up their "own" cup, such an approach to design also allowed each group to pursue a treatment of their own design within the framework of the larger investigation. Thus, scaffolding each small group to develop understandings of different aspects of the design process in their small group referential field, and then scaffolding personal⇔social ideas perspectival shifts to bring ideas from the small-group into the whole-class referential field, provided a means to support participation of all groups in an activity that might have seemed beyond the capabilities of some of the groups to accomplish on their own.

Reflecting on experimental design. Connie introduced this activity in a very different way from her introductions to the long-term prescribed experiments they had carried out previously. If the goal was for her students to engage in *designing an experiment*, then Connie and her students' instructional conversation would need to scaffold developing a shared understanding of a conceptual, *not* a procedural task. That is, their conversation would need to focus the joint attentional field on a mental process—the process of designing an experiment; and to begin making sense of this task, they would need to begin trying to find words to describe that mental task. There was no template, no rote procedure that her students could follow in order to figure out how to connect the steps of an experimental procedure with a hypothesis about a causal relationship such that the experimental results would confirm/disconfirm the hypothetical relationship. Connie and her students had to construct an instructional conversation that would help them begin to reflect on this very difficult intellectual terrain, a very different intellectual terrain from any that they had explored before during their two previous prescribed experiments.

Instead of beginning the conversation with an overview of the purpose of the experiment and a demonstration of the procedures that students would need to follow in order to carry out the experiment, Connie began this conversation with an *open-ended question*:

T:	*Let me ask you a question. OK?* If you had, as a scientist, if you had a question that you wanted to find an answer to, say you wanted to find out, you wanted to find out, find a cure for [pause] cancer
S:	[Calling out] AIDS.
T:	Or a cure for AIDS. OK, AIDS is fine, because I know that's on everybody's mind, especially since we're doing maturation. *As a scientist trying to find a cure for AIDS, what might be something that you would do? And I don't mean specifically, but what would be something that you might try to do?* [Several stds raise hands] [S1]?

S1:	Mix medicines up together?
T:	[Following up with same std] OK, what's it called when you mix medicines up together?
S1:	<….>
T:	[Following up with same std] But what are you doing if you're testing a bunch of chemicals and watching 'em and stuff, and trying to figure out what happens? What do you call that *process*?
S1:	Uh, an experiment^.
T:	[Continuing follow up with same std] Yeah, OK, [nodding, reaching out toward std with her hand] *you would DESIGN an experiment.* OK^. That was a good guess, just, you needed a little help getting it out.

(Effects of Acid Rain on Living Things: Seg 00:00:17 – 00:02:00, italic emphasis added)

In this discourse sequence, Connie orchestrated turns clearly designed to include her students in shaping the conversation. When a student suggested an area of particular student interest for possible scientific investigation, Connie incorporated the student suggestion into her developing scenario. She did not move quickly on to another student, when the first student did not provide the response that she had in mind, as often occurs in traditional recitations. Rather, she and the student continued to work together over three sets of turns to find student words that could appropriately describe what scientists do. Connie reframed the student's last response as "*designing* an experiment," rather than "*doing* an experiment" as the student no doubt had in mind. Then, with *designing an experiment* as the new topic of their conversation, Connie continued to call on students to add additional student ideas to the referential field:

T:	Yes. [pointing to std with hand raised]
S2:	Find out the main thing that caused it.
T:	OK, that's what you're trying to do is find out the main thing, but as I asked *S1*, how would you go about finding out what caused it? What would you do? Do you have any idea?
S2:	Experiment.
T:	OK, experiment. *S3*^.
S3:	Like, to find a cure for it, I'd like study the virus and then I'd try different medicines on it and stuff and see which one it would, it will react to.
T:	OK, you've *DESIGNED AN EXPERIMENT*. Exactly. You study it, you study about it, you study the bacteria or whatever, then you try to design some way to find a cure, some type of an experiment.

(Effects of Acid Rain on Living Things: Seg 00:00:17 – 00:02:00, italic emphasis added)

Such a conversation provided students with the opportunity to engage in personal⇔social perspectival shifts as they contributed their own ideas to the idea construction of the whole-class referential field, thus participating in the shared sense-making of reflectively putting their existing ideas and images of experience together in different ways to try to make shared sense of the meaning of a mental process.

Connie then guided the conversation through a review of their recent experiment exploring the effects of acid rain on non-living things, which then served as a foundation for a discussion of non-living versus living things and animals versus plants, which eventually led to the conclusion that they would design an experiment to test the effects of acid rain on living things and would use plants as the test organism. Connie then reminded students of another recent activity—designing rain collectors—and asked them what they might need to "consider" in designing their experiment, using similar terminology to the "design considerations" that had guided the design of their rain collectors:

T:	Remember, we DESIGNED our rain collectors? Well, we're going to DESIGN our experiment this time. And you'll get together in groups of two, and each group is gonna be given the job of trying to design some type of an experiment where they can test the effects of acid rain on plants, OK? *Now, let me ask you—can you think of some things that you might have to CONSIDER while you're designing your experiment?* We already know what the question is—what is the effect of acid rain on living things—in this case plants? *What are some of the things you're going to have to CONSIDER as you DESIGN your experiment? What are some of the things you're going to NEED as you design your experiment?* Come on, guys, what do you need for an experiment? Yeah^. [pointing to std with hand raised]
S2:	<A plant.>
T:	OK, you're going to need a plant. Now, does anybody see any plants in this room?
Ss:	[Calling out] No… Yeah… No… Maybe… No… No…
T:	OK, I tell you everything you need [big motion with hands] I'll be able to have in this room and I can actually have it today. So, we don't see any plants [making motion across front of classroom], so any ideas?
Ss:	[One student says "Oh!" and raises his hand; several stds point to the tchr's cart.]
T:	[Pointing to std who raised his hand] Yeah.
S5:	[Inaudible—std points to cart]
T:	Weelll, what's in there?
S6:	[Calling out] Dirt!
T:	[Tchr pointing/talking to *S6*, smiling] That's dirt, you helped me bring it in. All right, *S7*^.

S7: Seeds.

T: OK, we're gonna need seeds. What else are we gonna need for this experiment besides seeds? Yeah [pointing to std with hand raised]

S2: Water.

T: OK, we're gonna need water.

Ss: [Calling out] Sunshine!

T: Sunshine.

[….]

[Students continue to suggest things they will need for the experiment—people to do the work, soil, a place for the plant to grow, fertilizer.]

T: OK, yeah, we need plants, we're going to get the plants by growing seeds, we need dirt, we need something to grow, to put the dirt in, so when you're designing your experiment, just like a science fair project, you need to make *a list of the materials that you need* in order to grow, in order to do your experiment. ***So, that'll be one of your tasks, make a list of the things you need in order to do this experiment.***

(Effects of Acid Rain on Living Things: Segs 00:03:56 – 00:06:55, italic and bold emphasis added)

Connie again began this sequence with an open-ended question, but changed the question that initiated this extended sequence of student brainstorming from "Can you think of some things that you might have to *consider* while you're designing your experiment?" to "What are some of the things you're going to *need* as you design your experiment?" This change in question allowed Connie and her students to begin the design task with brainstorming a concrete list of materials, rather than an abstract list of design considerations.

Of interest in this introductory conversation are the very different discourse moves that Connie and her students orchestrated, and therefore the very different intellectual work that was done, within this opening segment of the lesson. Rather than closed statements conveying currently accepted scientific ideas or pre-defined procedures, Connie used open initiating questions and open follow-up questions/confirmations that acknowledged the contribution that a student response made to the on-going shared construction, but that did not convey that Connie had an answer in mind or that their shared construction had been completed. The goal of this conversation was a conceptual goal—for Connie and her students to begin to develop a shared understanding of what it meant to design an experiment, so that the small groups could proceed with the original thinking required to do the design on their own. This goal shaped a very different instructional conversation, as teacher and students grappled with "wrapping words around" what it meant to design an investigation—that is, as they worked together executing perspectival shifts from personal⇔social definition, and from description of procedural images to description of theoretical relationships, in order to co-construct a nascent shared understanding within the whole class and students' own referential fields of what it meant to "design an experiment."

Designing an experiment. The small group segment provided the opportunity for a perspectival shift in which Connie and her students had not engaged—a shift from talking about ideas describing a mental process to attempting to engage in carrying out that mental process in collaboration with their "study-buddy" partner. As Connie moved from group to group to scaffold the process, she established very focused joint attentional fields with each small group, helping the small groups begin to wrestle with what it means to design an experiment, with the intent that the small groups would eventually contribute the ideas they developed to the whole-group referential field:

S2: [Raises hand, initiates question] Mrs. Harvey. Can we draw it?

T: You can if you want to, drawing sometimes helps you get it a little bit more straight in your mind—but what are you going to start out with first, the very first thing? [*S2*'s partner leaning over to be part of conversation as well; *S8* turning around for adjacent group also to listen to the conversation.]

S2: A cup.

T: Well, what is the cup part of? If you're doing an experiment, first you come up with a question, then what do you have to come up with next?

S2: The answer.

T: Well, the answer's at the end, you got to do a lot of stuff in-between, what do you have to do in-between?

S2: <Decide what you're going to do.>

T: OK, and how do you do that?

S2: I don't know.

T: Well, in order to do an experiment, what do you need?

S2: < >

T: RIGHT. So that's a list of what? [pause] A list of [pause, nodding] materials.

T: [Turning to include *S8* from the adjacent group in the conversation] OK, your question is—what is the effect of acid rain on living things and we've already decided that we're going to grow plants. And that's all I'm going to tell you—the rest is up to you.

S2:	Ms. Harvey, Ms. Harvey, I got an idea, use two cups [using his hands to show the two cups], and then we pour acid rain [on the first cup, plain on the second cup], and when all that water comes out, test with pH paper.
T:	Write down your ideas and talk with [partner's name].
(Effects of Acid Rain on Living Things: Seg 00:10:52 – 00:25:59)	

It is interesting to watch the ideas develop as this group of three boys attentively listens to the exchange between one group member and the teacher, as the student moves from an understanding that they need a cup to beginning to visualize aspects of the experimental procedure. It is also interesting that the student's initial images of the experimental procedure clearly derive from an experiment that they did earlier in the year that also involved plants—the Grass Seed Experiment. Several groups bring their images from that experiment to this one, beginning to think about this experimental design by thinking that testing the pH of the "run-off" from their bean plants would advance their investigation. Having the opportunity to wrestle with which ideas in the referential field advance the conversation is a very important part of the intellectual work done by perspectival shifts from social⇔personal definition, which shifts were numerous in this small group segment.

Another group wrestled with the very important ideas of control and of what solutions they could use to simulate regular and acid rain:

S10:	[raises hand]
T:	[Walking over] Yeah.
S10:	Can we like test to see if regular water works better with seeds than acid water?
T:	What do you call it when you do an experiment like this and this is just ordinary regular water, ok, and this is an acid rain water? What do you call this, do you know what you call this particular… [*S11* moves chair so that he is closer to conversation]
S10:	Control^.
T:	Exactly, and that's definitely what you need. I'm glad you came up with that and I want you to make sure that you tell the class about that because that's really important and that's something that no one else has thought of—is having a control, watering with, our water, I tested my water at home, and it's about a 5.5, and what did we say normal rain was that was not acidic? Do you remember?
S11:	5.0.
T:	Well, what's acidic rain, what's the scientists' definition of acidic rain? That was on your test yesterday.
S11:	<Inaudible, shaking his head>
S10:	5.0 and lower.

T: 5.0 and lower is ACID rain.

S11: I thought you meant the thing when we were testing our <…>.

T: [Nodding, agreeing, looking at *S11*] Yeah. And regular rain's about 5.3 or up. So, 5.5 would fall right in that regular rain, so definitely we could use regular tap water as our control. But, you make sure you tell the class that. You're doing fine.

S11: We could use tap water for the acid rain.

S10: No.

T: Well, for the regular rain, to say this is how we would NORMALLY water the plant. OK, so that's your control.

S11: And then we'd use distilled water for the

T: And then, well, we wouldn't use distilled water, cause that's not normal. OK. We want to do normal rain, at least I would want to do normal rain and I would want to do acid rain, that's exactly what you have right here.

S11: How do you know when it's acid then?

S10: Test it.

T: Well, OK, that's a good question, how do you know when it's acid? How're you gonna get acid rain water?

S10: We'll collect it and find out a way to test it.

T: But what happens if it doesn't rain? [pause] I mean, right now there's no rain in the forecast. How're you gonna water your plants?

S11: With regular water, I guess.

T: Well, but then

S10: Regular water for the FIRST cup.

T: Yeah, what are you going to do about the SECOND cup, the one you want to simulate the acid rain water, what if it doesn't rain?

S11: Use lemon juice^.

S10: [Rolling his eyes disapprovingly] Lemon juice?!

T: [Tchr shrugs] It's not a bad idea. Lemon juice—is that an acid or a base?

S11: Acid.

T: *It's a possibility. [pause] Why don't you think about REAL acid rain, what's REAL acid rain made of? Think about it, OK^.*

(Effects of Acid Rain on Living Things: Seg 00:10:52 – 00:25:59)

Note that Connie scaffolded this group by asking probing questions, not providing answers, so that the students themselves could do the reflective work of evaluating the design possibilities that they were considering. Connie's final contribution to the conversation was an open-ended invitation to these two students to explore new terrain that the whole class had not yet had an opportunity to develop—the components of real acid rain, and whether the students could simulate acid rain by using those components in their experiment. Although this particular group did not take up her invitation, the ideas of a control and of simulating real acid rain had become part of the referential fields shared by Connie and the small groups, and therefore existed as potential tools to support their subsequent whole group sense-making.

The whole group sense-making segment, developing from this rich foundation of scaffolded reflection during the small group segment, included many extended examples of students adding design ideas to the whole-class referential field and of student voices providing extended explanations of those design ideas. In the following example, Connie explicitly drew the contrast between two possible design ideas—watering the seeds immediately with the acid rain solution or waiting until the seeds had sprouted to water them with acid rain—and asked students to select which procedure they wanted to use and provide a justification. Connie thus scaffolded whole-class participation in the reflective process of considering and evaluating two student-proposed design possibilities:

T: [….] Did anybody have an idea when they designed their experiment when they wanted to put acid on the plants?

[…] [Students offering some suggestions about when they would water the plants.]

T: *S3*^.

S3: [If it's our plant] I'm just watering it and watering it daily.

T: [Speaking to *S3*] OK, now, are you going to start using your acid solution on it right after you plant the seeds?

Ss: No.

S3: I don't know.

T: Shhh, I'm asking you, it doesn't matter to me, it's your experiment.

S3: Yeah.

T: OK, so you would, you would start watering the seeds and everything with the acid rain right at the beginning?

S3: [Nodding, looking at her partner]

T: OK, what about you, *S2*?"

S2:	I'm gonna wait til they start to grow, [wait til the plants come up] and just water 'em.
T:	*OK, why would, do you think it would be better to do that? I'm asking you, because we have two different points of view. S2 says water the seeds right from the very beginning, you say wait til the plants come up and water 'em. What do you think? You think there is a reason why you should wait?*
S2:	[Shaking his head "No"]
T:	*You don't think there is a reason why you should wait? Any idea why you might want to wait? S12^.*
S12:	So it can grow a little bit before you water it down with acid.
T:	OK, we're trying to find out what happens to living things. *S13*^.
S13:	To see how the acid, the acid rain affects the leaves and all that.
T:	OK, so if we wait til after it GROWS, then we can actually see what the effect will be on the LEAVES and the plant itself. *S3*^.
S3:	Yeah, but if you also start watering right when you plant it, then when, like the time limit that you already set is up, then you could dig up the seeds and see how it changed or something, cause it might be a different color.
T:	OK, that's a good idea, that's a VERY good idea. *S14*^.
S14:	If you wait until it, if you wait until it grows, you, ummm, if you DON'T WAIT until it grows, then it might not grow and then you won't be able to see the changes.
T:	OK, that's a good point, too. *S14* says that, you know when you plant seeds, not all of them come up, I mean we all know that. And what *S14*'s saying is, if we start watering [pause] right away, we're not going to know whether the acid rain did something to the seed or it was just a dud seed and didn't come up. That's what she's saying. *S3*^.
S3:	Just plant more than one then.
T:	OK, how many would you plant? How many seeds do you think you need? Now remember, it's a small cup, how many do you need?
S3:	Two or three.
S:	[Calling out] Eight or nine.
T:	Two or three seeds? OK, *S7*, your comment^.
S7:	Well, I don't think that if you water it right away, before it's sprouted out, that the seed might start, the plant might already start to lose its color while it's in the seed and then when it comes out, you <won't be able to study the effects because they probably all already happened>.

> *T:* OK, that's an interesting idea. *I think maybe we should let S15 [partner of S3], if that's what her group would like to do, maybe her group would like to try it, watering just the seeds from the very beginning. And maybe the rest of us, since the consensus from most other people, they'd like to grow their seeds and see their plants so that they can observe what happens, maybe the rest of us will grow our plants and not water with our acid until them.*
>
> (Effects of Acid Rain on Living Things: Seg 00:25:59 – 00:39:11, italic emphasis added)

Notice that Connie helped all of the groups to come to closure regarding which approach they were planning to use for their own design and to understand the various possible affordances of that particular design idea. However, she was very careful to leave both ideas in the referential field as legitimate design ideas that afforded exploration of different experimental questions.

Thus, as Connie and her students wrestled with understanding and then carrying out the task of designing their own experiment, they had the opportunity to participate in many opportunities for reflection that would provide patterns for future thinking and doing that would continue to shape their conversation—including engaging in perspectival shifts that provided an opportunity to wrestle with reflecting on "wrapping words around" mental processes, and an opportunity to consciously attempt to carry out the mental process that they had attempted to describe.

Conclusions

The research study yields both theoretical and empirical conclusions that are consistent with and add to current ideas in the literature.

Theoretical Conclusions

The theory development of the study adds to several important theoretical discussions in the literature.

The Role of Perspectival Shifts in Developing Shared Sense-Making

The study proposes a central role for perspectival shifts in developing shared sense-making. In particular, the study proposes that such perspectival shifts occur not only as shifts from one sense-making system to another along a single dimension of the **I**-space, but also as shifts across the dimensions, that is, as shifts among doing, thinking, and thinking about thinking.

The study itself was advanced by a number of important perspectival shifts that brought the ideas together in novel and productive ways—including (a) conceptualizing two fundamental human activities as making shared sense of unfolding narrative experience and coordinating action to respond to those shared interpretations, rather than entering the problem space through an examination of the intellectual tools that are the result of that shared sense-making; (b) conceptualizing a human shared sense-making system as a fruitful unit of analysis for exploring human interactions, and in particular, human instructional interactions, rather than using individual cognition or collective cultural activity as the fundamental unit of analysis; (c) conceptualizing teaching and learning as two mutually constitutive processes of shared sense-making; (d) conceptualizing instruction as a process of enculturating humans into processes of shared sense-making through legitimate peripheral participation in sense-making systems. This progression of perspectival shifts eventually led to a conceptualization of a theoretical "interaction space" and two ways to characterize that space—(a) the *n*-dimensional **I**-space and perspectival shifts along and across the dimensions of that space, and (b) an interconnected network of sense-making systems and mental models of those sense-making systems, and coherence processes that operate within and among those sense-making systems and mental models of those systems.

Toward a Synthesis of the Individual and the Social

Recent debate in the educational literature has focused on two fundamental questions of human cognition/learning: where is the mind (Cobb, 1994a, b), and how should learning be characterized (Anderson, Reder, & Simon, 1996, 1997; Greeno, 1997). Much of the discussion has focused on attempting to tease apart important, but subtle, distinctions among dichotomous perspectives—constructivism versus socioculturalism (Cobb, 1994a,b; Driver, Asoko, Leach, Mortimer, & Scott, 1994), cognitive versus situative learning (Anderson, Reder & Simon, 1996; Greeno, 1997), acquisition versus participation metaphors for learning (Sfard, 1998), and interaction versus intersubjectivity (Kieren, 2000; Lerman, 1996, 2000; Steffe & Thompson, 2000)—in order to engage in a meaningful discussion of human intellectual activity/development.

The constructivist versus sociocultural debate has focused on questions of whether the mind is most fruitfully conceived as located within the head of the individual or distributed across sociocultural context (Cobb, 1994b); whether human development proceeds through individual self-organizing effort or through appropriation of sociocultural practices (Cobb, 1994b; Minick, 1989), whether the telos of development is a fully independent solo thinker or a fully enculturated participant in a community of practice (Bruner, 1984); and whether learning involves active individual construction of coherent understandings from personal experience (Cobb, 1994b; Glasersfeld, 1995) or co-participation in meaningful social practice in sociocultural context (Cobb, 1994b). The cognitive versus situative learning debate has focused on whether learning is most fruitfully conceived as changes in the knowledge of an individual as measured by the individual's independent performance in various contexts, or as changes in patterns of participation in sociocultural activity (Greeno, 1997). In the situative tradition, learning has variously been conceived as cognitive apprenticeship (Brown, Collins, & Duguid, 1988); apprenticeship in thinking (Rogoff, 1990); and legitimate peripheral participation (Lave & Wenger, 1991). This difference in the conceptualization of learning leads to important methodological differences regarding whether learning is most fruitfully studied by decomposing individual cognition into its component structures and processes (and then reassembling the parts in various ways) or by examining complex activity/interaction in sociocultural context (and then examining the various roles that participants play in that activity/interaction) (Greeno, 1997).

A number of researchers have suggested that neither half of these various dichotomies provides a complete picture of human activity/intellectual development (Cobb, 1994a,b; Driver et al., 1994; Greeno, 1997; Kieren, 2000). Cobb (1994a,b; 1995) argued that it should not be necessary to choose between perspectives—that, pragmatically, mathematical learning can (and should) be viewed both as a process of individual construction as well as a process of enculturation into the practices of an intellectual community, and either perspective can simply be foregrounded as needed. In contrast, Lerman (2000) claimed that sociocultural psychology and radical constructivism have very different roots and orientations, and attempting to combine incommensurate theories leads to incoherence. Greeno (1997) proposed that what is needed is a synthesis of the separate lines of cognitive and situative research into one coherent theory of social interaction and cognitive processes.

This study follows the direction proposed by Greeno (and Vygotsky) and attempts to contribute to efforts synthesizing one coherent theory of social interaction and cognitive processes. The study develops a theoretical foundation for synthesizing individual and social perspectives by conceptualizing human intellectual development in terms of shared sense-making rather than individual learning/cognition. The study develops a model of shared sense-making that integrates an elaboration of Vygotsky's zone of proximal development with an elaboration of Tomasello's joint attentional and referential fields (Tomasello, 1999; Tomasello, et al., 2005), and with a broad definition of theory of mind. The model integrates the individual and the social as two mutually constitutive elements of a system of human shared sense-making, enabling representing the continuum of intermental and intramental interactions as envisioned by Vygotsky (1978, 1987). The study proposes (and also demonstrates empirically) that such a system of shared sense-making is an appropriate unit of analysis for exploring developing human understanding.

Tomasello (1999; Tomasello, Kruger, & Ratner, 1993) proposed that what is unique about human cognition may not be our individual ability to innovate, but rather our collective ability to "ratchet" innovations—that is, to distribute an innovation to other humans such that the innovation forms a new basis of shared understanding for the next round of innovation/ratcheting. Since the tools that individual humans are able to develop in isolation over the course of ontogenetic development seem to have little explanatory power in terms of understanding the successful survival of the human species, examining systems of human shared sense-making, and how such systems shape and are shaped by human culture, seems key to understanding human intellectual development ontogenetically and socioculturally.

Inquiry and reflection: Mutually constitutive interaction.

This study proposes a possible means of integrating processes of inquiry and reflection into the model of shared sense-making. The study theorizes that inquiry and reflection are mutually constitutive processes that play a key role in human flexible shared sense-making, enabling sense-making systems (individual and collective) to "open" to consider multiple possible options and then to "close" to the "best fit" option for a particular situation based on criteria such as reproducibility, coherence, and fruitfulness.

Conceiving of inquiry and reflection as fundamental processes of flexible human shared sense-making suggests that these processes may play an important role in the "ratcheting" that Tomasello (1999) proposed as one of the unique aspects of human social cognition. The study proposes that exploration processes such as inquiry and reflection provide the capability of coordinating multiple minds in the process of shared sense-making—multiplying the capability of human mental processing by systematically coordinating multiple minds to scan widely for possible options, merge multiple perspectives, and check for potential errors in processing.

This study proposes rethinking a previous strong association of inquiry with causal relations, suggesting that the essential difference between inquiry and reflection may have to do with systematic observation, rather than causal relations. The proposed mutually constitutive interaction between inquiry and reflection enables the important idea of reasoning from systematic evidence to enter the world of professional practice as a distinct construct (inquiry), while also enabling the important role of values and beliefs in framing human decisions and influencing human perceptions to enter the world of science as a distinct construct (reflection).

Conclusions: Empirical

The case study of mini-cases serves as a test case to illustrate the power (and the limitations) of using the theoretical frame as a lens to interpret shared sense-making in a classroom context. As such, the case study adds to an emerging empirical literature that conceptualizes teaching as an instructional conversation (Tharp & Gallimore, 1988) rather than as teacher enactment/student learning and that attempts to develop meaningful theoretical/analytical tools to characterize such classroom conversations (Ball, 1993; Herrenkohl, Palincsar, DeWater, & Kawasaki, 1999; Leinhardt & Steele, 2005; Palincsar, Brown & Campione, 1993; Rosebery & Warren, 1998; Wells, 1999, in press). Secondarily, the case study yields empirical findings regarding possible developmental trajectories of sense-making in inquiry-based classrooms, and affordances of and possible mechanisms by which inquiry-based instructional activities support shared sense-making.

Developmental Patterns in Shared Sense-Making

Perspectival shifts played an increasing role in shared sense-making across Connie and her students' year of scaffolded introduction to inquiry-based science instruction. The most common perspectival shifts initially were collective⇔individual realization, as students had the opportunity to enact prescribed experimental procedures in the classroom. These initial perspectival shifts seemed to provide students with a foundation of rich narrative images upon which to construct ideas; a strong student voice could often be heard as Connie and her students discussed possible reasons for unexpected results during these prescribed experiments. However, many students did not seem to have flexible control over these procedural images—they often did not seem to know which of the many details of these images were important to attend to or which comparisons across narrative experience might be meaningful to make.

Eventually teacher and students began to orchestrate additional perspectival shifts—and in particular, realization⇔ideas (description), action⇔ideas (explanation), and closed⇔open convergence/control (nascent inquiry/reflection). Interestingly, these additional shifts seemed to occur more frequently initially within the small group context, which seemed to provide Connie and her students with the opportunity to try out interactions that were more difficult to orchestrate in the whole group context. Ideas developed through perspectival shifts within the small group context were then often contributed by members of the small groups to the whole group referential field during whole group shared sense-making.

Both Connie and her students seemed to develop an increasing facility with establishing joint attentional fields and with elaborating referential fields through perspectival shifts over the course of a year of scaffolded introduction to inquiry-based instruction. In particular, both Connie and her students seemed to become more adept at developing and exploring multiple possibilities (nascent inquiry/reflection). Thus, their experiences with inquiry-based instruction seemed to begin to change the shape of their instructional conversation itself.

However, although students had developed a rich set of procedural images and had begun developing ideas and sense-making processes to help them make shared sense of those images, they had few opportunities to begin developing the overarching intellectual tools that would help them make sense of those images over extended time in powerful and flexible ways. For example, although they had participated in instructional conversations that provided nascent opportunities for engaging in inquiry and reflection, they had not yet begun to name and develop conscious (and therefore flexible) control over those tools. Empirical findings suggest that class periods filled with many short-term goals and objectives often leave little time for seeding and developing the powerful overarching intellectual tools that can help students find powerful ways to knit together (that is, make sense of) narrative experience over extended time.

Affordances of Various Instructional Activities

Empirical findings suggest that prescribed experiments can provide an initial basis for developing images of some aspects of investigation. However, results also suggest that prescribed experiments can be confusing for both teachers and students—making it unclear whether the purpose of an investigation is to (a) provide an illustration of known science concepts; (b) provide a controlled situation that enables students to practice selected components of an investigation; or (c) provide an opportunity to engage in the inquiry and reflection that characterizes an actual investigation. In particular, making sense of an experiment after it has been set up seems particularly problematic—impoverishing what can be learned from the narrative experience of setting up the experiment, potentially introducing sources of error into the experimental set-up due to lack of student understanding of the important goals/purposes of each step, and providing a misleading template for inquiry.

Affordances of Inquiry-Based/Project-Based Science

Empirical findings support the claim that inquiry-based science instruction—and in particular, project-based science instruction—provides rich environments for developing an instructional conversation. Engaging in first-hand investigations provided opportunities to develop the rich procedural images that can form the foundation for the dialectic between experience and intellectual tool development discussed above. However, empirical findings also indicate that providing opportunities to engage in investigations does not guarantee that inquiry and reflection will actually occur in interactions in the classroom.

Results also suggest that the focus of inquiry-based instruction—and in particular, project-based science instruction—on developing multiple interconnected collaborative contexts potentially provides important support for developing coherent shared meaning among the various contexts. However, developing coherence was not a guaranteed result of interconnected collaborative contexts. In this case, Connie invested considerable effort to ensure that the ideas generated in the small groups would contribute in important and positive ways to the whole group sense-making.

Thus, empirical findings indicate that inquiry-based instructional conversations do provide rich opportunities to engage in shared sense-making. However, results also suggest that several key elements must be in place if inquiry-based instruction is to realize its potential for supporting shared sense-making. First, the instructional conversation should provide multiple opportunities for different kinds of perspectival shift to support developing shared sense-making. Further, all participants in the instructional conversation must conceive of themselves and others as intentional agents engaged in shared sense-making—making shared sense of the goals and intended purposes of the intellectual tools being developed. Finally, and perhaps most importantly, instructional approaches are themselves intellectual tools. Without a clear understanding of the goals and intended purposes of the instruction, teachers and students cannot make use of inquiry-based instruction as a powerful intellectual tool—and the powerful dialectic between experience and idea development that is the potential of inquiry-based science instruction will not be realized.

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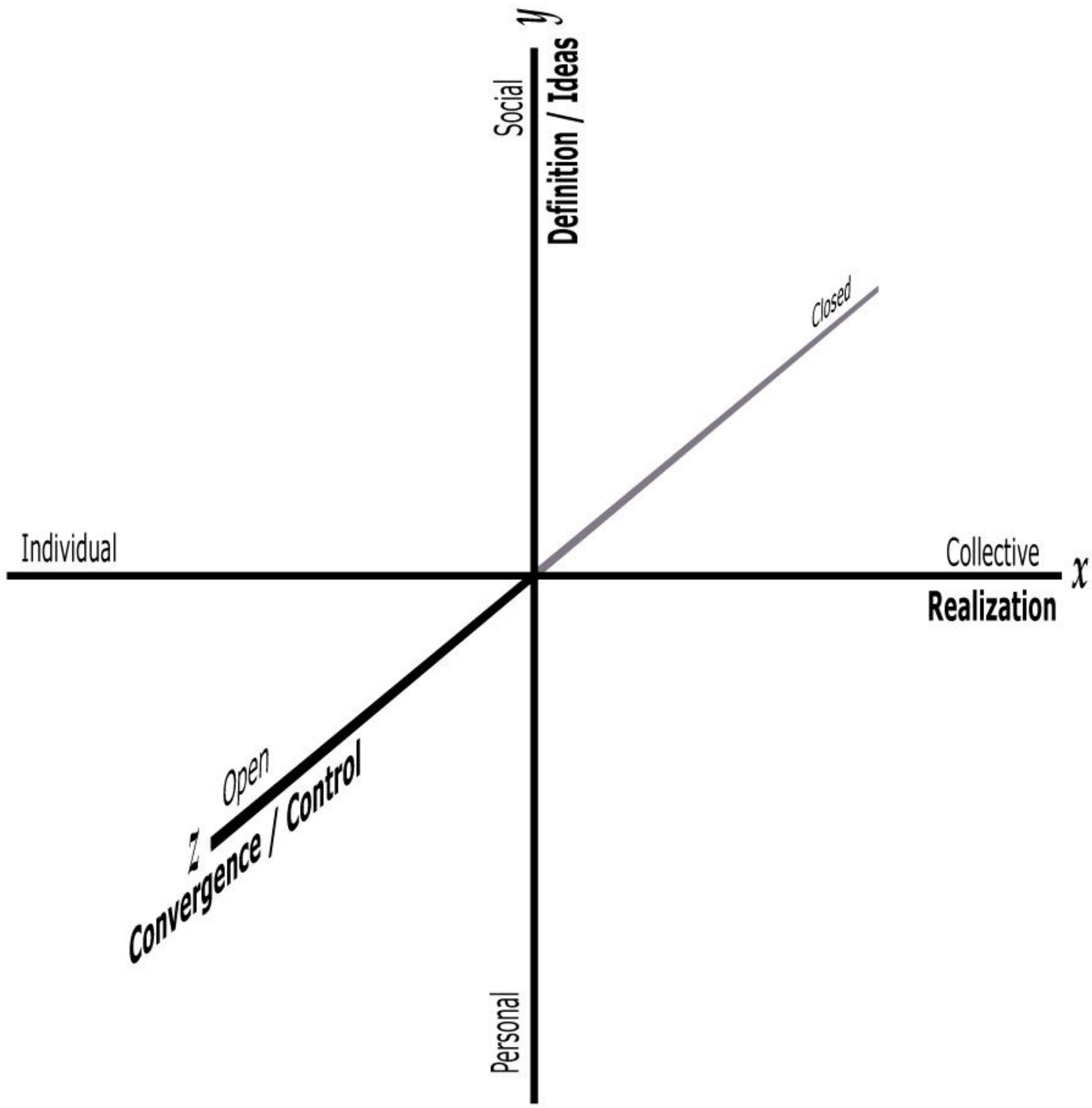

Note: A possible fourth dimension – affect – is not included within the scope of this study

Figure 1. 3-Dimensional interaction space (**I**-space).

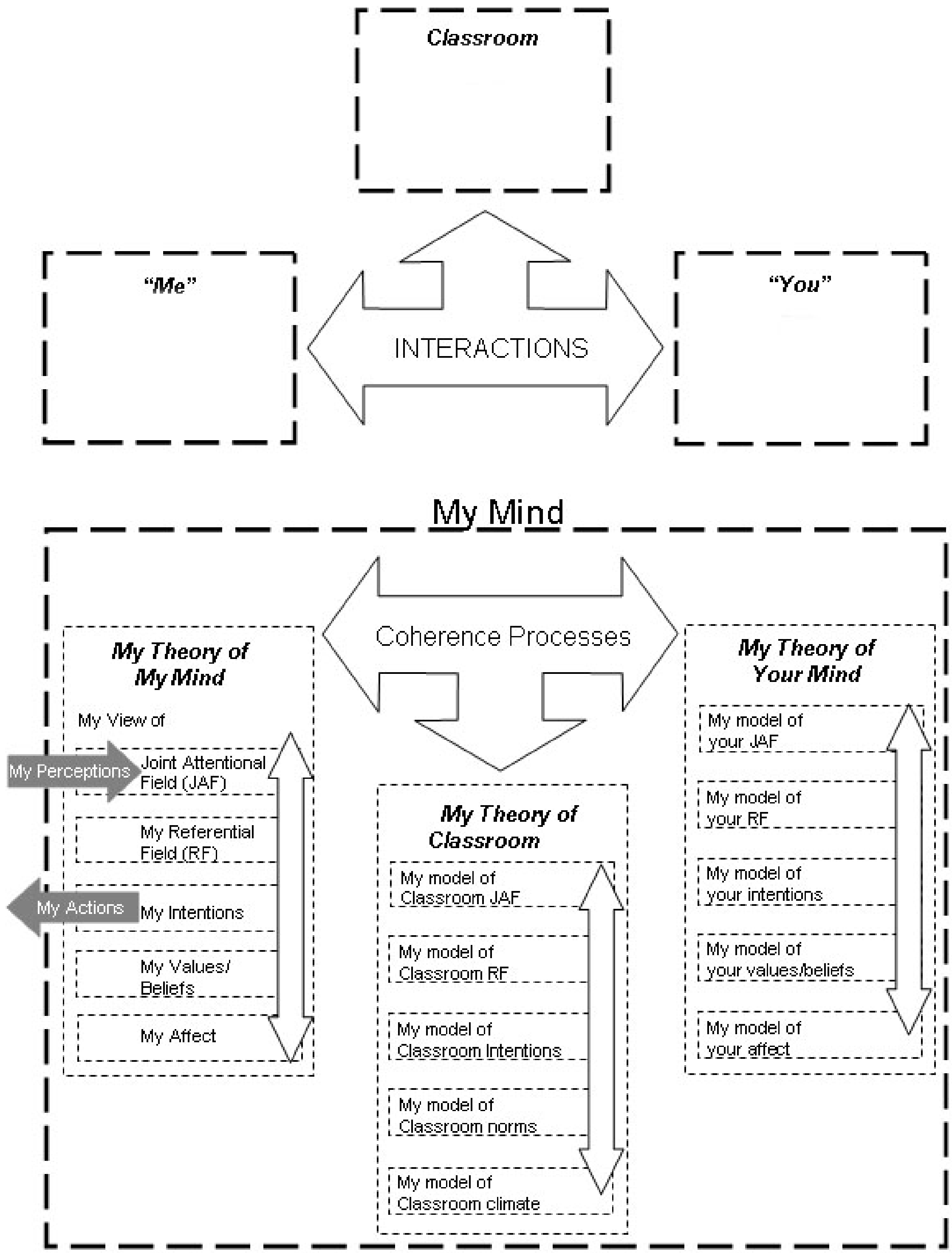

Figure 2. Conceptual structures of the **I**-space.

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