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Reflective inquiry with complex data: A case study of dispositional learning

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Introduction

Computers can bring to classrooms increasingly sophisticated tools for representing and organizing large amounts of information. To inform our efforts to design curriculum and instruction with which to take advantage of these tools, we must address a fundamental question: How do students learn to make sense of complex information through classroom inquiry?

The answer to a "how" question about learning must involve a description of a process of change for students. Becoming more adept at figuring out big datasets means changing modes of thinking and acting when faced with complexity – from less productive, to more productive. Dewey (1933) defined this change as developing a *reflective* mode of inquiry: "beginning with practical manipulations" of artifacts used in the classroom, but then "transferring interest to intellectual matters" (p. 224-5). Learning to make sense of complexity involves learning to reflect productively.

What does this process of learning to reflectively engage complex data look like? And how can we characterize this learning process in a given domain of inquiry? In this study we propose a conceptual framework for representing and analyzing changes in the nature of students' reflectiveness in classroom inquiry using complex datasets. The goal of the proposed framework is to identify factors that contribute to the development of more reflective dispositions in inquiry, and to examine how these factors interact to shape what is learned.

The need for new conceptual frameworks.

Research frameworks afford and also constrain our understanding of learning. One of the great challenges for educational researchers over the last decade has been to develop frameworks that represent learning contexts as more than bilateral interactions between subjects and interventions. Theories of learning must be grounded in an understanding not just of individual cognition, but of systems of activity in which those individuals act.

For example, Jean Lave (1990) draws attention to the inadequacy of an "expert/novice" framework for studying science learning in high school classrooms, in light of Eckert's (1989) culturally-informed framework for representing participation patterns of "jocks" and "burnouts" in high school science classes:

> If ... current theories of the learner and conventional interpretations of variations in students' performance in research settings are irrelevant and erroneous, we might worry about the power of research on learning to broaden our understanding of effective methods of teaching and learning in schools today. (Lave, 1990, p. 255)

Lave's criticism is that knowing and learning are situated – and we know too little about the situation, or how knowledge gets constructed through social interaction in the classroom. If we don't understand the activity of constructing knowledge in the classroom, our effectiveness at designing good interventions will suffer.

Conceptual frameworks for research on learning often assume linear relationships – such as when we study the impact of a certain curriculum design (or instructional strategy) on changes in student understanding. Such frameworks often ignore so many salient aspects of the activity context that they shed little light on how learning happens. On the other hand, very abstract frameworks – such as metaphors for teaching-learning processes – can provide valuable insights, but often do not enable us to represent the effects of particular elements within a learning environment.

Inquiry learning can be represented as interactions among factors in classroom activity systems. This type of factor-relationship representation can be thought of as a kind of modeling. Social and intellectual relationships in classrooms are not simple enough to model quantitatively, as we might model global warming or other eco-systemic processes, but the value of a model lies not only in predictive or computational functions. Models also are valuable as symbol systems for identifying relevant factors in a complex system, and for characterizing relationships and processes involving these factors. The framework developed here is intended as such a model for characterizing changing reflective inquiry dispositions, and with it we attempt to represent relationships among elements which are usually considered in isolation from one another.

Representing inquiry dispositions

Students' dispositions in scientific inquiry are often characterized as properties of the individual, such as an internal psychological state or ability, or a set of characteristics, beliefs, or understandings. These characterizations do not account for the interdependent nature of modes of thinking and activity contexts. Rather than defining reflectiveness as a local property of the individual, we suggest that reflective thinking is an emergent property of an individual's interaction with an activity system. To understand it, we need

to represent both characteristics of the individual, and characteristics of the activity system in which the individual participates.

Furthermore, the kinds of reflective thinking that we, as educators, want to instill in students are not usually generic or universal, pertaining similarly to all subject areas. Rather, they are dependent upon the domain of inquiry, or the family of conceptual connections that are the goals of curricular and instructional design. Therefore, to study the development of reflective thinking, our framework must represent not only the individual and the activity context, but also the mode of reflective thinking which a teacher and/or a curriculum designer intends students to develop.

So to study the process of students learning to think more reflectively in inquiry, we suggest that there are three arenas that we must examine within a common framework:

- an intended mode of reflective domain thinking;
- a system of activity within which we hope this mode will develop; and
- individual factors which contribute to a student's mode of participation in inquiry.

Each of these constitutes a context for the development of reflective dispositions. This study attempts to articulate these three contexts and their interrelations, to develop a framework with which to characterize changes in inquiry dispositions.

Prior research has shed much light on each of these three contexts separately, as they relate to reflective inquiry with complex datasets. Literature on scientists' thinking (e.g. Reif and Larkin 1991; Dunbar 1995), metacognitive strategies (e.g. Schoenfeld 1987; Kuhn 1993), and various domain analyses for designing curriculum (e.g. Tabak, Smith et al. 1996; Smith and Reiser 1998; Radinsky, Loh et al. 1999) provide valuable representations of particular understandings, inquiry skills, strategies, and habits of mind which we might want students to learn (context #1 above). Analyses of lesson structures (e.g. Johnson and Johnson 1982; Kagan 1992), socio-cultural activity systems (e.g. (Rogoff 1995; Polman 1997), and classroom discourse (e.g. Gutierrez 1993; Lin 1993) provide important models for representing the complexities of everyday classroom interactions (context #2). And literature on identity and culture (e.g. Eckert 1989; New London Group 1996), student motivation (e.g. Malone 1981; Dweck 1986), and student conceptions of science (e.g. Carey 1988; Sandoval and Reiser 1997) provide valuable insights into the worlds and minds of students (context #3).

The framework developed in this study attempts to locate these three contexts of classroom learning in relation to one another. This effort is important in that each research focus (on domain thinking, on classroom activity, and on student understandings) must define itself in relation to the others, in order to avoid some misleading assumptions. For example, curriculum does not act independently upon students to effect given learning outcomes. Students' dispositions and beliefs about curricular domains do not exist independently of classroom experiences. And the events of a day in the classroom cannot be well interpreted without considering both the instructional context, and participants' identities.

Recognizing the fallacy of these analytical pitfalls is not enough. As teachers and researchers, we need analytical frameworks that will keep us mindful of the interacting contexts that shape learning experiences. Individual teachers and students, the curriculum, and classroom activity exist in a tight relationship with one another. For these reasons, we propose an analytical framework representing interactions among the three.

Overview of this study

This study presents an analysis of one student's learning process, addressing the question: *How does this student learn to make sense of complex information through classroom inquiry?* This case is part of a larger study of students in three classrooms. This study of one student, LaTanya (a pseudonym), looks at her process of developing a more reflective inquiry disposition, and examines the relationship between this dispositional learning, and her changing domain understandings.

The primary relationship studied here is LaTanya's changing mode of participation in inquiry, and the developing small-group pattern of activity with her group partner David. This relationship – between the individual student's role in an activity system, and the group's mode of interaction with each other – is foregrounded in this study. This interaction was found to mediate the development of reflective thinking in the domain.

Other important factors affecting the development of reflective inquiry habits, including teachers' instructional strategies and curriculum designs, are backgrounded in the analysis. This is not to say that they are not important, but rather that their effects can be interpreted through the lens of student, and small group, participation patterns. Analysis of the same data, foregrounding teacher-student or student-artifact interactions, would greatly expand on the findings of this study.

We choose to focus on student role/ group interaction patterns as mediators of learning for two reasons. First, teacher and curriculum "effects" on student learning are the most common focus of educational research – this means that we often "hear" mainly what the teacher says, and "see" mainly the curriculum materials. As a result, we, as a community, may tacitly assume that instructional strategies and curriculum designs are the only mediators of learning. On the other hand, we have less awareness of how students construct understandings through discourse, and how the interactional patterns of students mediate what is learned.

The second reason for foregrounding student interaction patterns and modes of participation lies in the concept of *dispositional learning*. By focusing on how students develop a reflective disposition in work with complex data, we require a detailed picture of how students act. Whereas the accumulation of factual and procedural knowledge might be identified in interviews or tests, dispositional learning is observable only in changes in participation patterns. This means that we must have a foreground focus on how students act in day-to-day activities with data – most of which take place in small groups, and often not in direct interaction with the teacher.

This study presents an analysis of one student's development of reflective inquiry dispositions and understandings. First the conceptual framework is presented, overviewing the body of research on which this study builds. The framework itself is an outcome of the larger study from which this case is drawn, and it is presented in the form of an argument for attending to the three contexts of reflection in inquiry (the data context, the task context, and the role context). Particular variables are proposed for each context, which are used subsequently in the data analysis.

The data analysis presents a detailed account of one student's change process over the course of the enactment of the Earth Structures and Processes unit. LaTanya's increasing conceptualization of tasks with reference to relevant domain concepts is presented as a process mediated by her development of a "comfort zone" for examining data with her group partner. Learning outcomes are examined in light of this developmental process. The findings of the data analysis are then tied back into the larger research context laid out in the conceptual framework. The research questions are revisited, and four findings from this case and the larger study are proposed from the data analysis.

Context of this study

This study is part of a larger program of design research, seeking to improve the educational community's understanding of how students learn through inquiry with complex data. Incorporating complex datasets into classroom inquiry presents many challenges for students and teachers. Students tend to have trouble managing the large amounts of information they encounter in these environments (Audet and Abegg 1996), and managing the work of classroom investigations in general (Schauble, Glaser et al. 1995). When allowed to openly explore in data-rich environments, students tend to look through datasets in a haphazard and non-reflective manner, which significantly limits learning opportunities with these tools (deJong and vanJoolingen 1998).

The mode of work involved in making sense of complex datasets is often unfamiliar and disorienting for students. What is actually learned by students as they attempt to make meaning of confusing data is very difficult to predict, with a great potential for developing misleading conceptions through using reasoning strategies that are inappropriate to the situation (Chinn and Brewer 1993).

The present study is part of an effort to develop mutually-informing models of classroom activity and design approaches for using complex computer-based datasets in classroom inquiry. The Supportive Inquiry Based Learning Environments (SIBLE) Project has pursued this program of "classroom-centered design" for the last five years (Loh, Radinsky et al. 1997; Radinsky, Loh et al. 1999; Loh, Reiser et al. in press). Our work has centered on the design and use of the Progress Portfolio, a software environment for classroom inquiry projects, as well as various inquiry curricula that use complex datasets. This work is a collaboration with middle- and high-school teachers, primarily in Chicago Public Schools.

The present study focuses on enactments of a middle-school curriculum unit designed by SIBLE researchers and teachers, called "Earth Structures and Processes: Exploring earth's crust using models and data" (Radinsky, Loh et al. 1999). Participating teachers and researchers collaborated both in the design of the unit, and in developing instructional approaches during enactments. Earth Structures and Processes is a 10-week inquiry unit on plate tectonics and geological change, utilizing a variety of datasets on paper, in data visualization software, and on the Internet. The enactments took place in 6th and 7th grade classrooms in three Chicago Public Schools.

Conceptual framework

John Dewey placed reflection at the center of his model of teaching and learning, as a key piece of the process of making sense of experience (Dewey 1933). Reflection, for Dewey, was the connection between ideas and actions, and a key distinction between passive learning of facts and procedures, and a deeper level of experience from which to construct understandings. But what exactly is reflection?

What is reflection?

> Reflection ... is a purposeful movement whose end is understanding. And to understand something means to place it in the context of a system. If one is confronted with a topic, then the first thing to do is to resolve it into a question ...
>
> (Blanshard, 1939; quoted in Hawkins, Mawby et al. 1987, p. 277)

Blanshard's definition provides some useful starting points for our discussion. A "purposeful movement" distinguishes reflection from just continuing along with unthinking or routine activity. The link to understanding something "in the context of a system" implies that reflection can end with a connection between the object of one's attention, and some organized set of reference points. But what is the "purposeful movement"? How does reflection lead to understanding? And what does it mean to "resolve something into a question"?

In this section we examine the implications of the ways educators have talked about reflection, in order to sketch a model of how the reflective process might work, and why it might be important for learning from inquiry. We need a framework which can enable us to recognize it when we see it, to study the component processes of reflection, and to draw assumptions which can point us toward designs for instruction.

The most thorough model of reflection to date was proposed by Dewey in his 1933 book *How we think: A restatement of the relation of reflective thinking to the educative process.* Dewey's model of reflection, and its role in learning through inquiry, serves as a starting point for more recent discussions of reflection, its value to education, and how to promote it. We can think of this body of literature as addressing three questions that concern us here:

- What makes a person reflect?
- How do we make sense of things through reflection?

- How do we teach students to be more reflective?

These questions organize the discussion of reflection below.

What makes a person reflect? Curiosity, confusion, and "problems"

The act of reflection marks a change in mode of activity, from a familiar, routine mode of work to a more conscious thinking through of the situation. What causes this change to happen? Dewey suggests that the shift to reflection begins with a "difficulty or perplexity":

> When a situation arises containing a difficulty or perplexity, the person who finds himself in it may take one of a number of courses. He may dodge it, dropping the activity that brought it about, turning to something else. He may indulge in a flight of fancy, imagining himself powerful or wealthy, or in some other way in possession of the means that would enable him to deal with the difficulty. Or, finally, he may face the situation. In this case, he begins to reflect.
>
> (Dewey 1933, p. 102)

What does it mean for a situation to "contain a difficulty or perplexity"? Situations do not inherently contain these things – rather, perplexity is in the mind of the person experiencing it. Therefore we must look, not to the situation, but to the attitude of the person in it. What might lead a student to be perplexed by a situation? For Dewey, an initial answer to this question is: *curiosity*.

Curiosity is what Dewey called a "native resource for reflection" – an aspect of a person which could lead them, under the right circumstances, to reflect. Dewey proposed a continuum of kinds of curiosity. A basic form is a simple impulse to interact with our surroundings, like an infant putting objects in her mouth, or a youngster "getting into everything" – accumulating experience and raw information about the world. A second level is the more linguistic and social questioning of experience: Why are things as they are? This level of curiosity is based on the realization that "the facts which directly meet the senses are not the whole story" (p. 38). Both of these are predecessors to what Dewey called "intellectual curiosity" – the desire to construct coherent explanations for the things we don't understand.

Curiosity can initiate reflection. When we are presented with a situation which confuses us in some way, we feel unsettled – but just noticing this feeling is not enough to initiate reflection. There must also be "an intellectualization of the difficulty or perplexity that

has been *felt* (directly experienced) into a *problem* to be solved, a question for which the answer must be sought" (p. 107). This is the beginning of reflection – when a confused feeling has been turned by the mind into a "problem" (see Figure 2.1).

This "intellectualization" of a surprising or confusing feeling is similar to what Hibert et al have called "problematizing" (Hiebert, Carpenter et al. 1996). Following Dewey, Hiebert et al see the act of problematizing as the heart of reflection, and as a kind of experience which is often missing from the classroom. Problematizing is not just something that happens by accident, but can characterize a stance toward experience: "[T]hose who engage in reflective inquiry look for problems. They problematize their experiences in order to understand them more fully" (p. 14).

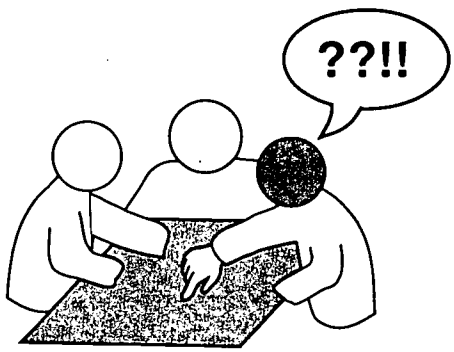


Figure 2.1. Students problematizing an aspect of an inquiry situation.

For Hiebert et al, even everyday things in the classroom can be problematized for inquiry. For example, students' strategies for subtracting numbers – commonly a process of rote application of memorized heuristics – can be made problematic through activities in which students compare different approaches to the problem. In this model, intellectually-stimulating questions do not automatically rise out of a situation ("tasks do not just appear"). Students can learn to make even the familiar problematic. The point is that students have agency in the process:

> ... students should be allowed and encouraged to problematize what they study, to define problems that elicit their curiosities and sense-making skills. (p.12)

The first piece of reflection, then, is an act of "defining a problem" – not in the sense of framing an explicit question, but simply by recognizing something that is not understood, and choosing to take an active stance toward resolving the confusion. What happens, then, once students "elicit their curiosities and sense-making skills"?

How do we make sense of problematic things? Suggestions, remindings, perspectives

Dewey contrasts reflection with "the disposition to pass judgment on the basis of mere custom, tradition, prejudice, etc, and thus to shun the task of thinking" (Dewey 1933, p. 34). We can avoid having a "problem" in a situation by passing these kinds of knee-jerk judgments, and this effectively kills curiosity about the situation. If curiosity is nurtured, however, then problematic aspects of the situation lead to Dewey's second "native resource" – *suggestion.*

Suggestions are ideas that occur spontaneously in the mind when curiosity has focused us on some "perplexity." Suggestions may come flooding in by the dozen, or trickling in slowly. They may cover a wide range of ideas about the situation at hand, or be very narrowly focused on certain features. The relationship of a suggestion that arises in the mind to the situation at hand may be superficial, or may involve a deep insight. But the suggestions that arise are the stuff from which we make meaning of the situation.

What happens next, when we are reminded of something, or an idea suggests itself in our minds? Meaning is made through the process of sifting through suggestions that arise, and selecting, examining, and re-shaping these suggestions until the mind comes to a state of resolution. This process may be conscious and orderly, or it may be instantaneous and sub-conscious. For Dewey, becoming more reflective means developing more *orderliness* of both the suggestions that arise, and the process of sifting through them. For people who are adept at reflective inquiry, suggestions arise and are worked through in "a single steady trend moving toward a unified conclusion" (p. 47).

Another way of thinking about this process of working through suggestions, or remindings, is as a number of different *perspectives* from which to re-consider a problematic situation. Hawkins, Mawby and Ghitman (1987) describe "critical inquiry" as a process based on the act of reflection:

> ... to stand back from a topic or problem and reflect on it from a variety of perspectives ... active development of a question or problem, and exploration of information in order to find an answer or develop a connected, meaningful perspective. (p. 277)

This is a larger-grain explanation of the same phenomenon of reflecting on a situation. A variety of perspectives are tried out, and a "connected, meaningful perspective" is actively developed – just as the initial problem was actively developed. The term "stand back" also suggests temporarily altering one's perspective – literally or figuratively – in

order to consider ongoing activity from a different vantage point. Multiple points of view can then be synthesized into a new understanding of the situation, much as we triangulate among points to identify a location in space.

Collins and Brown (1988) also equate reflection with adopting multiple perspectives on a situation – in this case, an action or a performance. By creating multiple representations of an experience – for example, videotaping a tennis stroke and watching it later; having a tennis coach model motions of the arm, or point out particular angles from which to view – we enable ourselves to look at the experience from different perspectives. The goal of this reflection is to make our "automatic" motions problematic, understand them anew from multiple perspectives, and then synthesize these perspectives into a new understanding, a new performance.

Becoming more reflective: Developing "native resources" and "dispositions"

These characterizations of how we reflect leave us with the question: What is involved in becoming more reflective, and how do we promote that development as educators?

Need to develop dispositions, cultivate "native resources"

Dewey believed that teaching students to think reflectively involved cultivating the "native resources" of students' personalities mentioned above – *curiosity, suggestion,* and *orderliness*. Each of these resources appears differently in each individual, as each student has a unique personality and unique thinking dispositions. The goal of instruction is to shape the native resources of each student to become more reflective:

> Training is that development of curiosity, suggestion, and habits of exploring and testing, which increases sensitiveness to questions and love of inquiry into the puzzling and unknown; which enhances the fitness of suggestions that spring up in the mind, and controls their succession in a developing and cumulative order; which makes more acute the sense of the force, the *proving* power, of every fact observed and suggestion employed. (1933, p. 55)

If education involves developing students' "sensitiveness to questions" and "love of inquiry," it is clear that Dewey saw this learning as a process of developing new habits and dispositions, not just acquiring new abilities and strategies.

This resonates with the concept of developing "habits of mind" for inquiry in a given domain, such as Perkins, Jay and Tishman's (1993) dispositional conception of

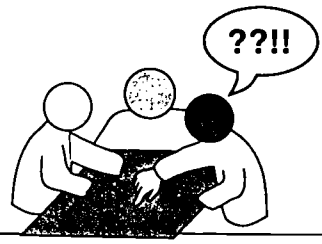
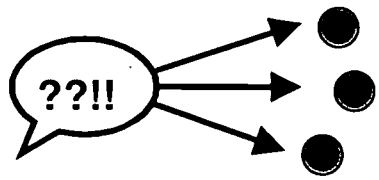
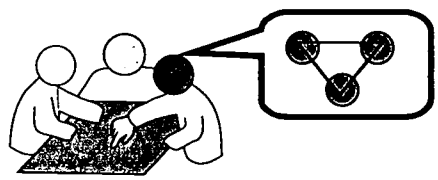
intelligence. This theory of dispositions goes beyond the uni-dimensional construct of *ability* which underlies many theories of "general intelligence." Perkins et al's dispositional model of intelligence consists of three elements: *inclinations* (a person's felt tendency toward behavior X, when the opportunity or need is identified), *sensitivities* (a person's alertness to an occasion to do X), and *abilities* (a person's actual capacity to follow through with X behavior).

The dispositional view is valuable for our model of reflection: we want students not only to be *able* to reflect, but also to have a *tendency* to reflect of their own accord. The emphasis is on the way the student orients herself toward experience, in addition to her capacity to exercise certain thinking skills. This is different from how we might think about teaching or assessing a particular skill or ability: the kind of prompting required to isolate the exercise of a reflective ability (e.g. asking a student to try to think back to any similar experiences she might have had in the past) obscures to what extent the student might have stepped back from activity herself to generate this kind of question without prompting.

Summary: A preliminary model of reflection in inquiry

From this discussion, we can distill four basic elements of what it means to engage in reflective inquiry, which can serve as a preliminary model, as presented in Table 1 below.

Table 1: A Deweyan model of reflection in inquiry

1) PROBLEMATIZING: Experiencing a sense of confusion or wonderment , and resolving this confusion into a more intellectual curiosity - an active intent to understand or resolve it	
2) SUGGESTION: Making connections between current experience and prior understandings or alternative perspectives, in an attempt to make sense of the problematic situation	
3) COORDINATION: Examining suggestions that arise in the mind or in discourse about this curiosity, and attempting to impose some order or resolution to these suggestions and subsequent experience, to resolve the confusion	
4) DISPOSITIONAL LEARNING: Over time, developing habits of mind which better focus curiosity toward coherent questions for inquiry, better focus suggestions toward potentially-useful connections, and create more orderliness in the process of constructing understandings	

Three contexts for reflection on activity with data

Starting with this Deweyan model, we can begin to examine in more detail the kinds of situations in which we want students to become more reflective. Classroom "situations" are complex – they involve many levels at which we can try to understand activity. Much of our talk in educational research assumes one level at which thinking happens, the "dominanat script" of the curriculum (Gutierrez 1993; Gutierrez, Rymes et al. 1995), without accounting for the other contexts of classroom activity where students' minds might well be occupied.

We propose three referential frames for thinking about classroom activity during any given lesson which are important contexts of reflection: the "data context," the "task context," and the "role context." These are three arenas in which the act of reflection in inquiry requires definition.

The "data context" is a representation of a mode of reflective domain thinking intended by the teacher and/or curriculum designers. The "task context" is a system of activity in which we hope this mode of thinking will develop, through instruction. The "role context" is a system of individual factors which contribute to a student's mode of participation in inquiry and other kinds of classroom activity. Before examining each of these three contexts in detail, we discuss the rationale for characterizing activity in multiple contexts.

Rogoff's sociocultural framework

The identification of three contexts in which to understand classroom activity builds on Rogoff's (1995) sociocultural framework for characterizing development. Rogoff suggests that learning through activity is best understood by attending to three planes on which development happens: apprenticeship, guided participation, and participatory appropriation . These three planes are supersets of the three contexts of reflection (data, task and role) proposed here.

The "apprenticeship" plane deals with the relationship of classroom practices to those of other communities outside the classroom, practices to which students are meant to be apprenticed. The apprenticeship plane "examines the institutional structure and cultural technologies of intellectual activity" (p. 143), as students become adept at using the "cultural tools" of a community. The "data context" proposed below is conceptualized as one instance of this apprenticeship plane – one family of conceptual tools which students are meant to learn to use. In the "data context," curriculum and instruction attempt to build a relationship between the practices of middle school students and the practices of geophysicists – one of many kinds of "apprenticeship" that are occurring in classroom activity.

Rogoff's "guided participation" plane characterizes concrete and observable practices of students and teachers. It serves "as a way of looking at all interpersonal interactions and arrangements" (p. 147) that mediate daily activity. We are concerned here with how students deal with each other, with their teacher, and with the "stuff" they are using – the artifacts of inquiry.

> Guided participation is ... an interpersonal process in which people manage their own and others' roles, and structure situations ... in which they observe and participate in cultural activities. (p. 147-48)

This plane of analysis is the place where the intended process of apprenticeship to a domain's way of knowing – embodied partly in curriculum and instruction – meets the "ways of knowing" of individual students. This is where "the rubber hits the road" – where we observe how activity mediates learning. Dispositions, reflective or not, are manifested in activity on the plane of guided participation. The "task context" of reflection, proposed here, is a representation of the guided participation plane. It proposes particular elements of activity which can be observed in order to study reflection.

Rogoff's "participatory appropriation" plane is where we look for evidence of conceptual and dispositional change of individual students. This context interacts with each of the others, as learning is mediated by activity, and also by conceptions of domain thinking embodied in curriculum and instruction. Changes in students' own understandings and beliefs may become more or less approximated to the domain concepts embodied in the data context. In other words, the extent to which students are actually "apprenticed" to the data context is mediated by their participation in the task context. Thus we look to students' changing roles in activity – where the "role context" meets the "task context" – as the site of dispositional learning.

In the three sub-sections that follow, the constructs of "data context," "task context," and "role context" are developed in detail.

The "data context" – a domain-centered focus

The "data context" is the family of things and ideas that characterize the "way of knowing" in the domain of inquiry which we want students to learn. The data context is a representation of what we want students to think about and figure out: domain concepts, sets of data for them to study, the real-world items which data represent, and models representing all of these things (see Figure 2.2). These make up the declarative facts students are supposed to learn: that volcanoes are formed along subduction zones, which look like *this;* that earthquakes happen at plate boundaries, which are *here;* etc.

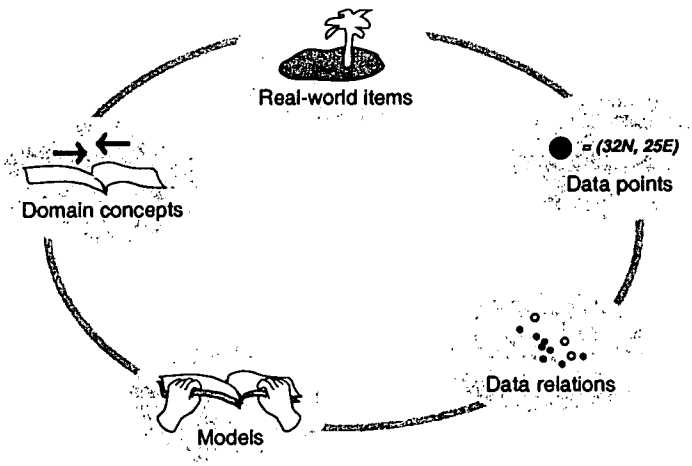


Figure 2.2. The "data context" of inquiry situations: elements of the domain's "way of knowing."

Reflection within the "data context" is the process by which we want students to build a connected set of understandings in the domain. We want them to problematize one element, such as a pattern in a dataset; to use the other elements, such as real-world items and domain concepts, as points of reference for making sense of the problematic pattern; and then to build a meaningful connection among these elements of the situation.

For example, a student might wonder why there is a cluster of earthquakes that happened close together along the Japanese coast (problematizing a data pattern). She might think about (or find on a map) what is there in that part of the world – a range of mountains and islands, including Mt. Fuji, and a deep underwater trench (suggestion of real-world items). She might remember, or be told by a group-mate, that subduction zones are where one plate slides under another, making a trench and a mountain range (suggestion of a domain concept).

These two "suggestions" might then become connected with the problematic data pattern, forming an initial connection which builds the student's understanding in the domain. That data pattern becomes linked with the real-world referents and the domain concepts, forming a (potentially) coherent case which can be built upon through further inquiry. This is one level at which we want to promote reflection – so that students will construct these kinds of connections among elements of the data context, forming mental models from which they can make sense of data and its referents.

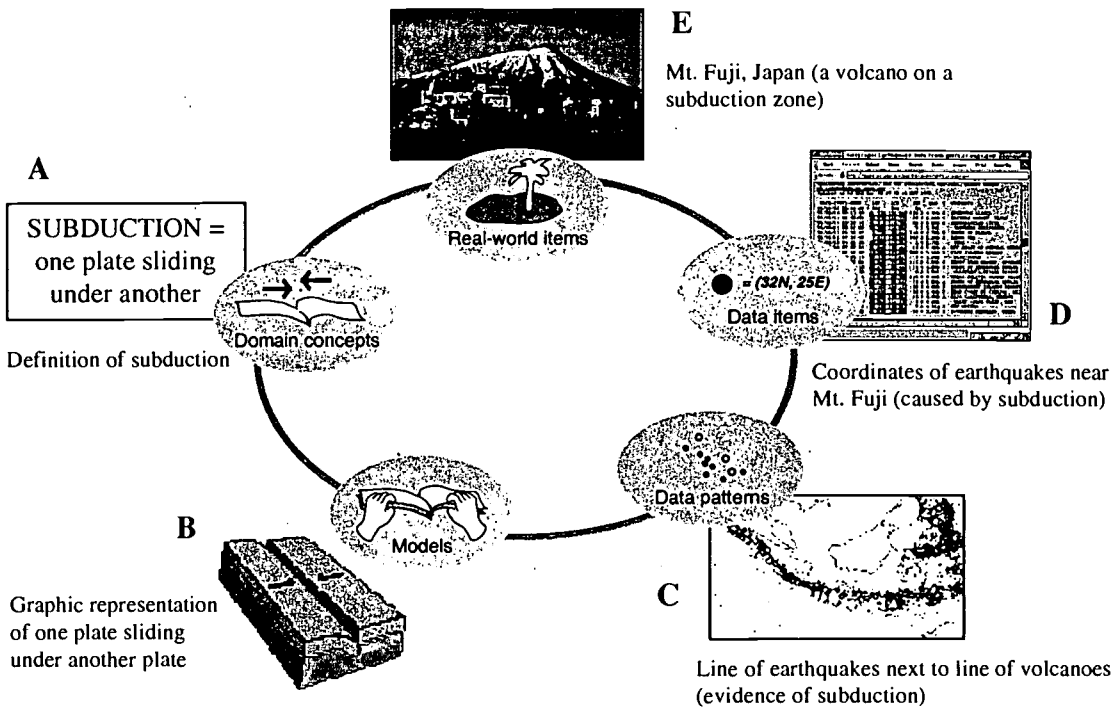


Figure 2.3. The Data Context, annotated with particular things students are meant to learn.

This representation of the data context can be used to represent a productive mode of reflection in the domain. For example, Figure 2.3 shows how particular facts about subduction – concrete learning objectives – can be represented in the Data Context. A student should be able to explain the *concept* (element A) of subduction as one plate sliding under another. She should be able to identify, produce, or use a *model* (element B) representing this concept – a visual or tactile representation of the relevant elements of subduction (plates) and their interrelations (movement, movement toward one another, one sliding under the other). Furthermore, she should be able to explain how the model illustrates the process of subduction, using other relevant domain terms such as "plate" (connection of elements A←→B).

The data context is a map of the conceptual territory within which students are to learn to reflect. We call this level the "data context" because learning in this context involves becoming able to make sense of data. This is the context in which many curriculum designers assume students are doing their thinking during a lesson. Learning means building understanding of domain concepts, and becoming accustomed to connecting data with its referents and with abstract concepts.

The "task context" – what students do

Within a given inquiry task, students must make sense of the elements of the data context above – data points, domain concepts, etc. Instead of considering these things only as abstract targets for reflective thinking, we now consider the role of reflection in shaping learning in the context of an inquiry task. The "task context" starts to attend to the complexity of activity – what are students *doing?*

Following Progressive traditions, many inquiry curricula – and much cognitive research – center on designing appropriate tasks for students to pursue in order to learn (Gitomer 1994), with attention to the kinds of declarative and procedural knowledge they will need to develop in order to accomplish the task. The selection of good learning tasks, based in detailed domain analyses, is a central concern of problem-based learning approaches (Hmelo, Gotterer et al. 1997), as well as "cognitive apprenticeship"-style instruction (Collins, Brown et al. 1989).

Schauble, Raghavan and Glaser (1993) state that "the specific importance of reflection is its role in consolidating the development of new strategies" (p. 22). Students must stand back from their inquiry task to problematize and evaluate the strategies they are using, connecting them with perspectives such as the goals of the inquiry. Reflection is a mechanism for the self-regulatory skills of maintaining goal-orientation (i.e. "holding in mind the goals and sub-goals [of] scientific discovery"), and self-evaluation during experimentation.

In order to study students' reflection in inquiry work, we must define the relevant factors which shape the "problem space" (Lesgold, Lajoie et al. 1992) within which tasks are defined. Our theoretical framework must represent the major factors that shape students' engagement in inquiry tasks – the things that make it more or less likely for a student to adopt a reflective stance toward a complex dataset.

We propose that there are five elements of a classroom activity system that combine to define an inquiry task. Rather than defining tasks as the set of predefined goals, objectives, and assigned actions described in curricular materials and/or a teacher's verbal charge (such as "Use red and blue markers to draw the plate boundaries that you are sure of and unsure of, based on the earthquake data"), we propose five elements of the activity system that jointly define a task. These are:

- students' conceptions of the activity they are doing

- action decisions taken by students
- the teacher's guidance (actions meant to mediate students' work)
- patterns of interaction among participants in group activity
- artifacts and materials used (including curriculum materials such as lesson plans and worksheets)

Each of these elements of the task context, like those of the data context above, represents something that can be productively problematized by students, as they make sense of inquiry. The graphic depiction of the activity system in which tasks are defined (see Figure 2.5) places a group of co-participants together within the "task context" circle, to suggest that understandings of tasks are co-constructed through activity rather than pre-formed in one student's mind.

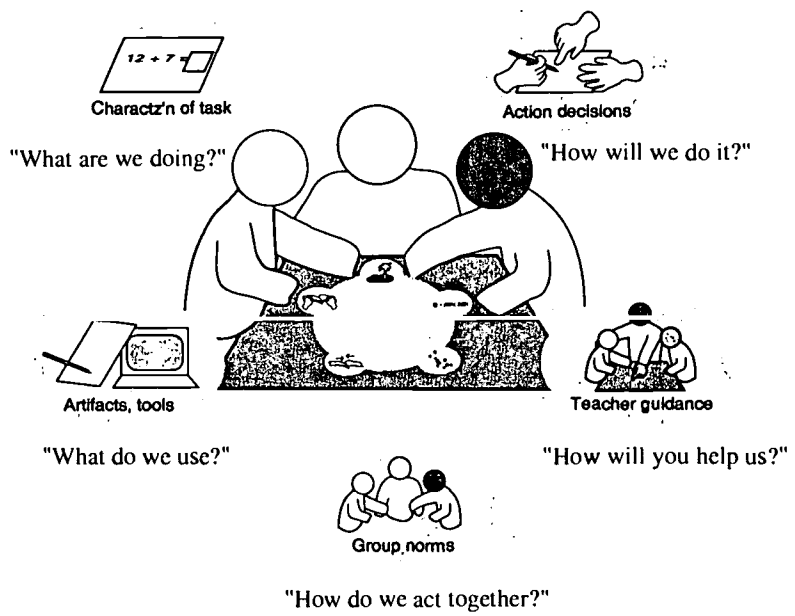


Figure 2.5. The more inclusive "task context" – tasks as an activity system

Students' conceptions of the task

Curriculum designers' conceptions of inquiry tasks do not necessarily define the meaning that those tasks have for participants in activity. The definition of the *enacted* task, as

distinct from the designs embodied in curriculum materials, is emergent in classroom activity. What do students think they're doing?

Conceptions of the task are often explicitly problematized by students – "What are we doing?" The answer to this may change from minute to minute, and may sometimes be difficult for an observer to determine. But it is crucial to identify how students are thinking about their own current activity, in order to track the development of more reflective dispositions. Evidence of students' conceptions is found in the words they use in discourse, and especially in patterns of engagement in a variety of activities over time.

In the data analysis that follows, we will see how characterizing individual students' participation patterns over time enables us to understand a great deal about their conceptions of particular curricular activities – their personal and negotiated characterizations of tasks. This might sometimes include a student understanding of their current activity that is wholly separate from the curriculum – e.g. gossiping about friends. Within this construct, the notion of being "on-task" and "off-task" becomes more nuanced, as we see the range of student conceptions of tasks. The essential approach proposed here is holding the nature of the enacted task problematic for ourselves as researchers, rather than assuming its definition based upon the official curricular script.

Having defined the curricular task as an emergent property of activity, we must re-conceptualize the cognitive construct of *strategy*. The term "strategy" implies a combination of actions and goals – what one does in order to accomplish some given end. we propose that we should not assume known goals of activity, and that we should instead attend to the relationship between what is observably *done* (action decisions), and students' apparent conception of goals underlying these actions (conception of task).

Action decisions

Action decisions and the talk around them often reveal a very domain-irrelevant conception of the task, but one which we nevertheless want to be able to represent. Also, students' action decisions sometimes suggest approaches that are relevant to the domain in unexpected ways, different from the strategy intended in the curriculum or instruction. The actual actions taken by participants in activity provide evidence of how they conceive of their current task.

Action decisions, often negotiated explicitly in the group, are a common focus of reflection – something that can be problematized in the process of making sense of

activity. In this sense they are an important part of this context in which reflective dispositions can develop. Becoming more reflective can include a greater tendency to hold action decisions problematic.

This framework has several benefits. For one, it allows for the fluid and co-constructed nature of the meaning of classroom tasks – students' action decisions over time add up to an evolving understanding of "what we are doing." A less-problematic "task-strategy" framework leads us to assume that all students "plotting earthquakes" believe that they are plotting earthquakes, which is manifestly not so.

Secondly, by focusing on the constructed meaning of tasks in activity (rather than only the intended), we have a more balanced view of the work of curriculum design. Studying action decisions and characterizations of tasks around our designed materials gives a broad picture of how learning can happen. Given the improvisational nature of classroom activity, we are well-served by understanding a wide range of task-conceptions that can be enacted around our materials, rather than only the extent to which the intended task-conception was or was not realized.

Teacher guidance

Whether she is present at a given moment or not, the teacher shapes the construction of the meaning of tasks in many ways. She is one participant in activity, but moreso, she is a dominant force affording and constraining many kinds of participation by students. For a study focused on teacher-student interactions, the "Teacher guidance" element of the task context might become a context in itself. Most aspects of students' group experiences – down to the actual constitution of each group – are mediated in some way by the teacher.

In this study of small-group inquiry activity with data, the "Teacher guidance" element represents those interactions with the teacher that mediate how the group conceives of the inquiry task at hand. The teacher's interventions themselves can become a focus of student reflection. What she says can be problematized by students ("What did she mean, 'Tell the story of the plate?'"), or can be referenced later in making sense of a some other problematized element ("See, that's like when she said it was going under"). On the other hand, they can follow the teacher's guidance as they understand it, without making it problematic. The framework for this study represents teacher guidance as a series of interactions with student groups that can mediate reflection, and also the process of developing domain-relevant reflections on the teacher's guidance.

Group interaction patterns

As Doyle (1983), Hiebert et al (1996), Stigler and Hiebert (1998), and others have shown, the norms of interaction among participants mediate how problematic students might find a given concept, task, or artifact. Examples of this mediation often illustrate how the teacher's norms of engagement of students, embodying her expectations for activity, promote or constrain problematizing on the part of students.

But it is important to note that this is true for emergent patterns of interaction among students as well, not just the "official" norms of the classroom. Just as there are global norms of participation in a given classroom, greatly mediated by the teacher, there are also normative patterns of engagement in ongoing student-group interactions that promote and constrain reflection. These emergent norms of small-group practice are constantly being negotiated and evolving, mediated by the teacher, by the students, and by the artifacts used in activity.

These emergent interactional patterns can be considered "norms" in that they are implicitly imbued with a certain value by the group as it adopts them. In a group with an interactional pattern of always joking, serious discussion may be explicitly devalued and ridiculed as a violation of the unwritten norms. Like more explicit "official" classroom norms, such as "All students are expected to contribute at least one question," small-groups' emergent norms can also be identified, such as "We're not supposed to disagree about action decisions."

The data analysis that follows will illustrate how these interactional patterns can be reflected upon by students; how they mediate conceptions of tasks and artifacts; and how they mediate conceptual learning. Group interactional patterns are an important element of the task context of reflection in inquiry.

Artifacts: materials and tools

Finally, we come to the actual "stuff" of the curriculum: designed artifacts, tools and materials which students work with. We introduce this element last, to underscore the departure intended here from a curriculum-dictated framework for studying classroom tasks. My claim is not that designed curricular materials are irrelevant to activity and learning, but rather that they must be understood in their proper relationship to the process of learning through activity. They constitute one element among many that mediate students' construction of the meaning of tasks.

In research frameworks for studying the effects of curricular designs on learning, we often equate the curriculum materials with some others of the distinct elements of activity which we have separated here: e.g. tasks, data items, data patterns, domain concepts, and models. The data analysis that follows will show how the relation of particular artifacts to students' conceptions of tasks, and to the intended domain of inquiry, is always problematic. Establishing connections between curriculum artifacts and the abstractions of the data context is a goal, not a given, of instruction.

Artifacts are potentially very significant mediators of learning. Their value should be assessed in terms of the extent to which they are problematized by students, invested with domain-relevant meanings, and incorporated into conceptions of that day's task that involve the data context. This is in contrast with viewing artifacts as agents in the classroom which cause learning, or fail to cause learning. Since artifacts are incorporated into cultural practices, we must disentangle our understanding of the affordances of their designs from our understandings of the other mediators of the cultural practices themselves (Stigler and Hiebert 1998). The construct of a "task context" (rather than simply a "task") is meant to help us disentangle artifacts from other mediators of sense-making.

Summary of the "task context"

The five elements of the task context are representational tools for characterizing classroom activity, without limiting ourselves to the assumption that this activity is related in a particular way to our domain analysis, or to particular modes of thinking (i.e. scientific reasoning). We can analyze participation in activity, including but not limited to the exercise of particular reasoning strategies and meta-strategies.

The constructs of the task context provide the basis for characterizing activity, and changes in patterns of activity over time. However, in order to characterize students' learning over time, we need a representation of their states of knowledge, abilities, and dispositions. The representation of learning for a given student lies at the next level: in the "role context."

The "role context" – defining learning from the learner's perspective

The "role context" expands outside of the task on the table, or the current focus of activity, and examines the elements of a student's subjective experience in the classroom which are likely to shape her participation in the activity system. At this level we can

characterize change in individual students, in relationship to the ongoing patterns of activity in the "task context."

In the task context, we defined activity in terms of patterns of interaction between people and artifacts. But beyond these observable actions of students and teacher, there are invisible factors that shape the nature of students' participation in classroom activity. These are the elements of the "role context" of classroom activity. It is in this context that we look for changes in student activity that would suggest the development of *dispositions* and *understandings*. We will discuss five elements of the "role context" of classroom inquiry here, and these will lay the groundwork for the characterization of changes in student participation – i.e. development of more reflective dispositions – in the data analysis section below. The elements are:

- Students' conceptions of classroom norms: "How are we supposed to act?"
- Student roles, or participation patterns in activity: "What do *I* do?"
- Student identities: "Who am I?"
- Student understandings and beliefs: "What do I know?"
- Prior experiences: "What's happened before?"

Each of these elements shapes students' tendency to be more or less reflective in classroom activity, as represented in Figure 2.6, and in the discussion below.

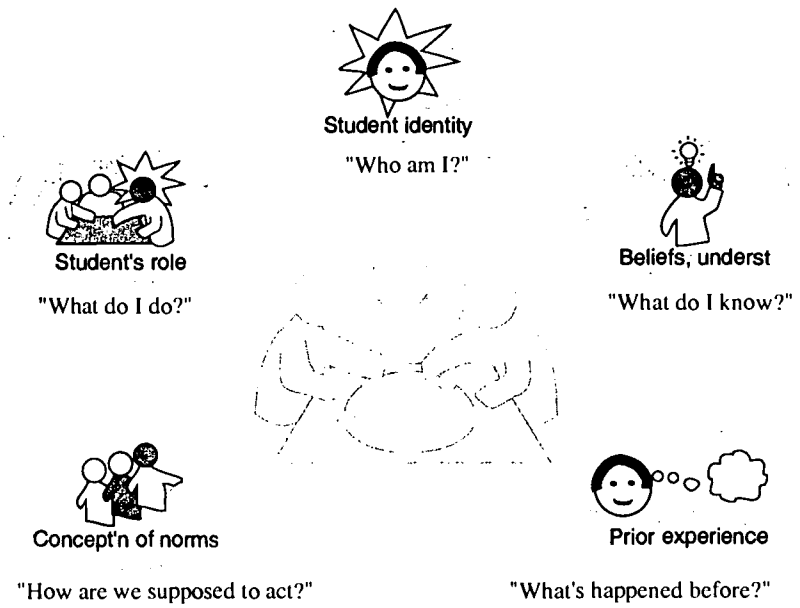


Figure 2.6. The role context: Factors influencing individual students' dispositions in classroom activity

Perceived norms of classroom activity

Every classroom has its own unwritten *norms of activity* – implicit cultural rules by which members of the class make meaning of the language of task assignments. Classroom norms answer the implicit question, *"How are we supposed to act?"* These norms determine who is expected to talk, when, and how; what is "good enough" work, from whom; what behavior is acceptable and unacceptable, from whom; etc. Classroom norms, more than any designed curriculum artifacts, shape what kinds of products students are likely to create; what kinds of discussions are likely to happen; and ultimately, what kind of learning will take place.

Some of these norms may be explicitly discussed, even written down; some are dictated to students by the teacher or the school administration. Many norms are determined by the cultures and sub-cultures which intersect in the classroom (Bronfenbrenner 1979), and may well be invisible to all participants within those cultures. However, other norms of activity are co-constructed by the participants in a classroom on a daily basis. All participants in activity co-create the classroom's norms of participation, through their interactions. Some of these norms are explicit, but many are not – participants are often unaware of the unwritten rules by which they interact on a daily basis.

Hiebert et al (1996) point out that the cultural norms of the classroom ultimately determine the extent to which a problem has reality for students:

> We propose that reflective inquiry and problematizing depends more on the student and the culture of the classroom than on the task. Although the content of tasks is important, the culture of the classroom will determine how tasks are treated by students ... Given a different culture, even large-scale real-life situations can be drained of their problematic possibilities. (p. 16)

Norms of activity shape student reflection in a number of ways. They determine to what extent stepping back and thinking through a problem is acceptable classroom behavior – this kind of questioning may be highly valued, or it may be thought of as evidence of stupidity, not knowing the answer. Norms determine what kinds of things may be considered problematic – is it OK to question the logic of a domain concept we're supposed to learn? They also determine how the artifacts of inquiry work are likely to be thought about – is our data map something we should keep after it's finished, to look back at if we need it later? In this way norms of activity greatly shape opportunities for reflection in classroom inquiry.

Classroom norms are not a focus of the data analysis *per se*. However, students' conceptions of these norms – that is, students' characterizations of the patterns of activity they perceive around them – do play a significant part in shaping the roles that are adopted. These conceptions are not norms in the sense that we usually refer to: explicit terms of engagement and modes of participation encouraged in classroom activity (Kagan 1992; Hiebert, Carpenter et al. 1996; Stigler and Hiebert 1998). But we use the term "norms" because this distinction may not be meaningful to students – the patterns of activity that see and react to are their conceptions of the valued practices of the community. In this sense, in the individual's role context, perceived norms are what matters.

Student roles in activity

As norms of activity are co-constructed, all participants adopt their own *roles* in that activity. These roles are shaped by the classroom norms, and in turn they shape the norms as well. Every teacher knows the extent to which even a single student's mode of activity can shape the definition of "acceptable behavior" in a class – for the better, or for the worse!

Roles of participants change over time, and vary across types of interactions. A student, teacher, or researcher in a classroom may adopt several different roles over a 15-minute period. Some roles are explicit, and even designed beforehand – such as the role of "Reporter" for a cooperative-group activity. Other roles are adopted implicitly or subconsciously – such as the role of "Tension-Breaker" when a student makes a comment that keeps another student out of conflict with the teacher. A student's role is their implicit answer to the unspoken question, *"What do* I *do?"*

The role a student adopts in a given mode of activity is a manifestation of her disposition toward that activity, at that point in time. Becoming more reflective in inquiry means adopting roles that include making things problematic, and seeking connections among elements of the inquiry situation. Many common roles which students play can preclude reflection – while other roles, which might not be thought of as "academically successful," can provide surprising opportunities for reflection.

For example, if a student is playing a brainy role of "She Who Knows the Answers," this role may make it unlikely for her to step back and puzzle over something confusing. A student who is playing a jokester role of "Comic Relief Provider" for his group will probably be constantly on the lookout for ridiculous or anti-school connections to the current activity, but perhaps not for connections to domain concepts, personal understandings, or data patterns. A student who is playing a resistant role of "Teacher Challenger" might be very likely to notice inconsistencies in a domain concept explained by the teacher – an opportunity for reflection, as the concept is made problematic. Her role in this situation might allow for reflective connections between the explanation's inconsistency and her own understandings about the world – or it might lead her only toward confirmation of the teacher's flaws.

In these ways, students' roles in activity are closely tied to the development of reflective dispositions toward inquiry with complex data. Student roles shape group interactions as well, and in turn shape other students' roles. These two related constructs – *norms* and *roles* – shape the ways that students think about everything within the "task context" and "data context" discussed above. Of course, norms and roles do not exist in a vacuum either.

Student identities

The role that a given student adopts in activity is shaped not only by the classroom norms, but also by their own *identity*, or sense of themselves. Fuson (personal

communication, 1998) relates the development of productive roles in classroom activity to the development of a student's self-image as one who can participate in meaning-making activity. Learning, in the largest grain, is a process of changing identity.

A student's sense of self in the classroom is tightly interwoven with all the other contexts in which she has an identity – her cultural and ethnic identities, her family identities, her peer-group identities, and her identities in a host of other socio-historical contexts of which she may not even be aware (Wertsch 1985). Each of us inhabits many different "life-worlds" (New London Group 1996) in each of which we have ever-developing and inter-connected identities. The construct of identity answers the implicit question, *"Who am I?"*

Identity and role in classroom activity are clearly tightly connected, and they influence each other. If a student sees himself as a smart and capable boy, one who deserves recognition, he is likely to adopt a role in activity in which to achieve success and be recognized for it. If a student sees herself as an instigator of conflict, one who doesn't take shit from anybody, she is likely to adopt a challenging and confrontational role in classroom activity.

Conversely, the roles a student assumes in classroom activity can shape their identities in other contexts. If a student has great success playing a clever joking role in the classroom, this may shape her sense of self in other contexts as a funny and entertaining person. If a student finds that he can identify interesting anomalies in data sets in a series of activities, he may more frequently adopt the role of "Pointer-Outer," making spontaneous observations to his group. This in turn may shape his sense of self in other contexts as a person who may notice things others do not.

Learning has been described as *development of an identity of mastery* with respect to the practices of a community (Lave and Wenger 1991; Rogoff 1994). This definition makes clear the tight relationship among identity, role in activity, and learning. These connections between role and identity are where we develop our long-term learning goals for students – not for acquiring particular skills or bits of information, but for becoming a more confident and able person. In the present study, the big-picture learning goal for students is to develop a sense of themselves as *one who can look at a complex bunch of information, identify interesting problems, and figure them out.* This is what it means to have a reflective disposition with respect to inquiry with complex data – at a level above the particular strategies required for analyzing a particular dataset.

Student beliefs and understandings

An important aspect of a student's identity, and one that shapes the roles she will play in classroom activity, is her sense of what she herself knows, believes or understands. This may be thought of as her epistemological identity, or sense of herself as a "knower." This identity shapes understandings and beliefs, or the answer to the question *"What do I know?"*

One's own beliefs and understandings can provide valuable material for reflection, assuming a role and an identity which allow one to reflect upon them. The more a student has developed her own understanding of a domain or a phenomenon, the more material she has to work with in making sense of complex data during inquiry. If she has heard and thought a lot about volcanoes, the information she already knows can be a valuable resource in figuring out concepts and data patterns encountered during inquiry. On the other hand, some of her understandings may make it more difficult for her to figure something out – for example, if she believes earthquakes happen only on land, she may get confused when she has to plot earthquake data in the ocean. As we will see, this confusion can be problematized, and lead to reflection – or it can be dropped, and lead nowhere.

Cognitive research has explored students' understandings and beliefs in relation to accepted domain concepts – comparing "folk understandings" of "novices" with "expert understandings." In the framework proposed here, we conceive of this comparison as the relationship between a student's understandings, and the understandings embodied in the data context. The point of instruction is to change each student's understanding of the world, in such a way as to create observable mappings between that understanding, and a coherent set of understandings which is valued by a community of inquiry.

Of course beliefs and understandings exist on many levels other than the domain of inquiry. The representation used here for "beliefs and understandings" lumps them all together within one construct. This is not to minimize the importance of understanding the complexities of how students see the world, but rather to suggest that these beliefs and understandings are one of several elements which jointly constitute students' performance in class. They must be understood in the context of the other elements of the role context.

Prior experiences

Prior experiences shape all of the other elements of the role context: one's conception of classroom norms, one's own roles in activity, one's sense of self, and one's own beliefs and understandings. Each of these things represents the cumulative history of a student's prior experiences, both within and outside of the classroom.

Prior experiences shape understandings and beliefs. A student who has lived in Los Angeles, or has visited family in Mexico City, may understand what an earthquake is in an immediate and personal way. Another student who has made a "continental drift" puzzle in 3rd grade may understand what a tectonic plate is, in another way. These prior experiences are potential "targets" for making connections when a question or confusion arises during inquiry activity (Dewey 1933; Schank 1990). They can provide a bridge between current experiences in inquiry activity, and the student's own understandings – a student may be reminded of a prior experience, and in the process make a connection between the earthquake data in front of them, and their own knowledge that earthquakes can happen in Mexico.

Prior experiences also shape how students perceive, and contribute to, the norms of classroom activity. They provide the expectations on which these norms are based, and thus also shape the roles students are likely to adopt. What has happened before provides "scripts" for activity over time (Schank and Abelson 1977; Gutierrez 1993; Gutierrez, Rymes et al. 1995). Prior experiences have the potential to be valuable resources for reflection, depending upon a student's conception of a given task, her role in activity with respect to reflection, and the norms of the class and the group in terms of relating classroom realities with other contexts.

Summary of the role context

The long-term goal of instruction in the role context is not just the development of new roles in classroom activity – it is a positive change in a student's sense of self, in particular their identity as a *knower* and as an *inquirer*. The construction of a series of experiences to support this identity-development is a long-term goal of instruction throughout the school year. Norms of classroom activity are a context in which we hope designed artifacts can help shape the development of students' "identities of mastery," not just in the domain of earth science, but in the many contexts of a student's life. Strategies and meta-strategies for making sense of earth science data are only one piece of this larger learning goal, one component of the school year's experiences.

In the present study, the role context is backgrounded, except in its most direct interaction with the task context: the changing roles, or interactive modes, of students as they participate in inquiry activity. Student beliefs and understandings are discussed only in assessing the relationship between their understandings of the domain, and the data-context understandings intended in the curriculum designs. Student identities and conceptions of the norms of the classroom are mentioned in analyzing their developing roles in activity, but are not a focus of the data analysis.

Understanding this role (or identity) context of learning is of utmost importance for educational research (Bronfenbrenner 1979; New London Group 1996). Students' beliefs and understandings (e.g. of scientific inquiry, or of a particular field of study), and students' conceptions of classroom norms (e.g. ways students think about group work), are often treated in the research literature as separate from the constructs of identity, prior experience, and role in activity. These approaches are valuable for the light they can shed on patterns of student thinking and understanding, but do not provide an ecologically complete perspective. The interactions among the constructs proposed here can give a fuller picture of how patterns of understanding and sense of self mediate the processes of learning through activity.

Summary: A framework for studying reflection in inquiry

The three-context framework outlined above is intended to provide constructs necessary for analyzing students' interaction with, and learning from, a curricular unit. The top-level instructional goal for the unit – furthering the development of reflective dispositions for investigating complex data – required an analytical framework for tracking dispositional change. Furthermore, it required a framework which could at once represent particular domain understandings, and also particular students' identities. These two points of reference come together in the daily practices of classroom activity. The constructs of "data context," "role context," and "task context" are meant to account for these three considerations.

The interconnection among these three planes is represented in Figure 2.7, which shows how the task context, representing guided participation in activity, brings together the other two contexts.

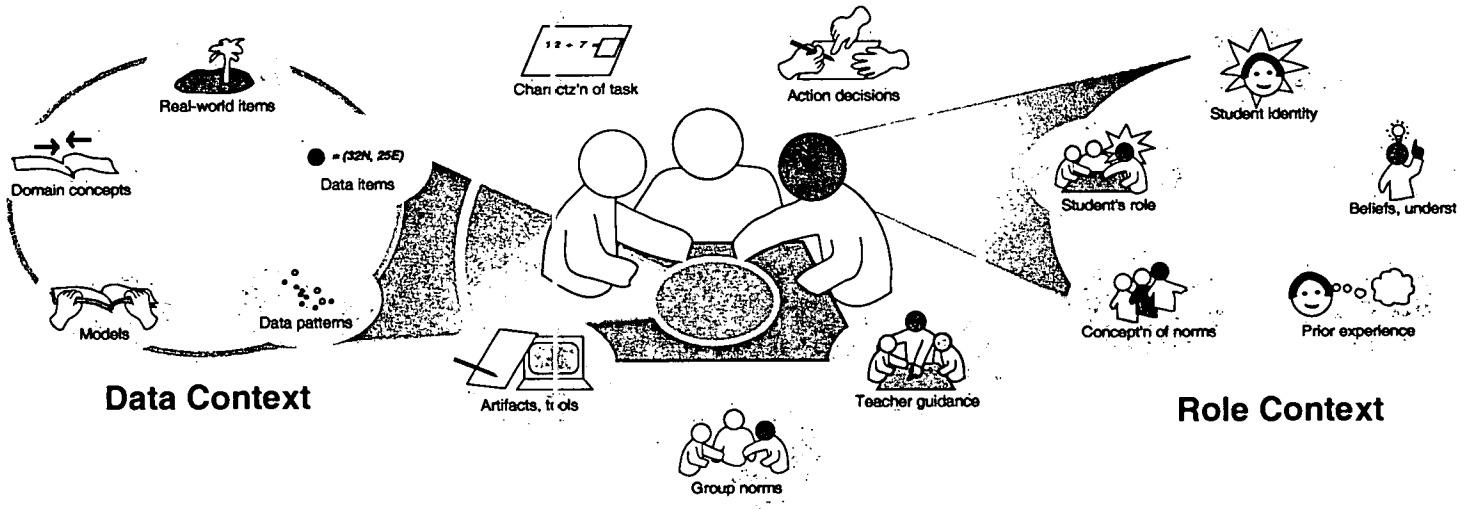


Figure 2.7. Three contexts of reflection in classroom inquiry with complex data.

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Design of this study: research methods

This section describes the methods used for studying activity. Four aspects of methodology are addressed here:

- Description of the research site and participants
- The level of analysis for studying activity
- The data collected
- The process for analyzing the data

Research sites and participants: classrooms studied

Daniel Boone Elementary School

Boone is a large, overcrowded school on the north side of Chicago, with about 1,200 students in a building built for 900. The neighborhood it serves is a predominantly immigrant community, with large South Asian, Middle Eastern, and Central European populations. There are bilingual classrooms for several language groups.

The demographic breakdown of the 7th grade class studied is:

29 students total:	13 girls, 16 boys
US-born white:	24%
South Asian:	21%
European immigrant:	17%
Middle Eastern:	14%
African American:	10%
Latino:	10%

Ms. Mundt-Leimberer teaches math and science to this group, as well as to an 8th grade group. The two classes each are in her room for half the school day (alternating mornings and afternoons on alternate days), and that time is divided between math and science. A student teacher worked with Ms. Mundt-Leimberer throughout the unit, leading a few of the discussion activities, though her main responsibilities were for activities outside the unit.

Students are grouped into different table groups (five to seven students) over the course of the year. They are also put into various small groups (two to four students) for particular activities – a student might alternate between two or three different groupings in the course of a week's activities.

Level of analysis: Focus on small groups

In studying classroom activity, we could choose to focus on several different levels of analysis – teacher-student interactions, teacher-whole-class interactions, individual student activity, the small group, the table group, etc. Each of these interactional spaces was found to be a space in which reflection happened, and each is important to understand. The data analysis for this study focuses primarily on the phases of classroom activity in which students worked in small groups at their tables, or at computers. The other main modes of classroom work – whole-class discussion, individual student work, and various modes of teacher-student interaction – are kept mainly in the background.

Background levels of analysis: Whole-class and individual students

This limiting of data analysis to small-group work was a difficult decision. In each class studied, there were many rich examples of reflective talk in whole-group discussions. In fact, this topic could be another study by itself. These discussions clearly shaped students' learning very significantly, and were the primary venue in which local learning experiences from the small groups were tied back to larger domain concepts for the whole class (see (Tabak and Reiser 1997) on the role of whole-class discussions in supporting classroom inquiry). The facilitation of these discussions is a subject of great interest to teachers and researchers alike.

However, the nature of these whole-class, teacher-facilitated discussions is such that the thinking of individual students is hard to study. Students are constantly prompted by the teacher to make particular connections between observations and ideas. Discourse moves along quickly, with the teacher making frequent strategic decisions on how to direct the flow.

The examples of reflection that can be drawn from these discussions are many, and they are often very impressive in themselves. But each student says few things, even in the longest discussion, and many students remain invisible. Many comments are adventuresome, shot-in-the-dark reflections, and they do not always connect to the ongoing work with data which is the heart of the curriculum unit. This mode of

adventuresome thinking and wide-ranging discussion is clearly very important to learning through inquiry, but does not give as clear a view of the relationship between curriculum designs and reflection on data. For these reasons, this rich set of data is backgrounded in the present analysis.

Reflection during individual student work is also backgrounded here. There were many instances in which students worked individually in what appeared to be a mode of deep thought, and many examples of individual work products that showed reflective thinking around data. However, individual work does not provide the bread-and-butter of this kind of classroom research: talk! There are many moments on videotape in which an individual student looks intently at a screen full of data and says, "Hmmm!" This suggests that they are reflecting on *something*, but it doesn't give us much from which to analyze their thinking processes, so individual reflection is also in the background of this analysis.

Rationale for studying small group activity

A research focus on small group work is very valuable to researchers and teachers. It is valuable for learning about students' roles for participation in classroom activity, as these roles are constantly negotiated and co-constructed by students in their "table talk." It is valuable for teachers, in that the majority of small group work at any one time happens without the teacher being present: while she or he is working with one group, the others are working independently. This research on modes of small group work provides a window on what teachers usually don't see in the classroom.

The level at which we have chosen to study the development of reflective thinking is the level of the small group of two to five students assigned to work together. Some advantages of this level of analysis are:

- A focus on small groups enables us to study peer interactions, a major influence on student activity and thinking, without having to account for *all* peer interactions in the entire classroom – only the most immediate.
- Small groups can mirror the ethnic, gender, and academic diversity of the class, giving a micro-perspective on these larger issues. The focus group in each class was set up in this way with each teacher. The analysis of students' participation in these small groups can shed light on larger issues of diversity and participation in the classroom.

- Small group work is a common and very useful configuration in classrooms, especially for facilitating inquiry with complex datasets – in the case of computer-based data, small group work is essential. This makes the small-group context for reflection a very useful one for educators to understand.
- Group-work can be *designed* – teachers can use design principles such as those in the cooperative learning literature (e.g. balancing positive interdependence and individual accountability (Johnson and Johnson 1982)), and awareness of individual students' needs, to shape interactions within groups. Therefore understanding how reflection manifests itself in the small group can potentially lead to group-work design principles.
- We use student discourse as our primary data on thinking, and discourse is co-constructed by nature. Therefore it is often difficult to attribute a particular disposition strictly to an individual, but rather to the interaction between individuals. The majority of interactions between students, both academic and social, happened between members of the same table-group.
- Small groups have an observable life cycle in the classroom – they change over time, accomplish milestones, and experience crises. This gives the group-level analysis validity as a research construct, and also makes it easy for teachers and researchers to talk about student activity and learning with a set of shared observations around each group. Group-level events become useful organizers of knowledge about the individual students in the group.

For these reasons, we have chosen to track two to three small groups in each class, which together make up one table group, as they go through the unit. Each individual student is considered at the level of her *changing role in group work with data*, and each group is analyzed as a *context for the development of reflective modes of thinking.*

Data collected

In each classroom one table group of four-to-seven students was set up, in collaboration with the teacher, to be a focus group. These groups were made to be representative of the diverse members of the classroom, including ethnic and gender diversity, and a range of academic performance levels. We made a point to include students who tend to talk (i.e. not the quietest students), to ensure enough discourse data to provide evidence of students' thinking during group activities.

A researcher was present for nearly every day of the enactment in the Boone classroom. We gathered six kinds of data during the course of the enactments in each classroom, from which to characterize student activity: field notes, videotape of class sessions, artifacts of student work, videotape of pre-post student interviews (individual and group), audiotaped design meetings with teachers, and videotaped reflection meetings with teachers.

Field notes from class sessions

Field notes documented changes in modes of classroom activity, problems and successes with particular lessons, passages of interesting discourse and activity, etc. The field notes were used to focus later analysis of the videotape.

Videotape of class sessions

Videotape was recorded for every class attended. The camera focused on the whole room during whole-class sessions, on the focus group during group-work time, and on individuals in the focus group during individual work time. (At Boone two cameras were used, to document both computer activity and table activity.) Videotapes were logged with summary information of activity during the period, and later used to generate verbatim transcriptions of discourse during focus activities. Episodes for transcription were identified from the field notes and the tape logs.

When table groups broke out into smaller sub-groups of 2 or 3 students, the camera followed one small group from the focus group, selected on the basis of interesting interactions in the groups observed in the class up to that point. Therefore not all small-group work was recorded, though we tried to get representative footage of small-group work from each sub-group at the focus table in each class.

Artifacts of student work

Photocopies, photographs, and scanned images of the focus students' work products were gathered: science journals, worksheets, maps, models, drawings, computer files, and other assignments. This dataset was used for triangulating assumptions about students' thinking around particular activities based on classroom discourse.

Interviews with students

Two kinds of interviews were conducted with focus-group students before and after the unit at Boone and Inter-American. (At Hayt only group interviews were done.) Individual interviews were developed to find out students' conceptions about the earth's crust, and to prompt them to make observations and explanations from GIS-generated datasets (volcano locations). Small group pre-post activities (3 students each) were developed to observe students' patterns of participation in group inquiry with complex data. Each activity used different printed GIS demographic datasets, and asked students to make observations from the data, then to use the data to conduct a mini-inquiry task.

These two interviews provided information about the following:

- students' domain conceptions before and after the unit
- students' abilities and dispositions to generate questions, observations, and explanations from complex datasets, before and after the unit
- students' roles in working with complex datasets in both a collaborative work context and an individual work context, before and after the unit

The protocols for the individual and group interviews are attached as Appendix A.

Videotaped reflection meetings with teachers

At least once during each enactment of the unit, and once after each enactment, we met to view selected video-clips and/or artifacts of classroom activity. We discussed observations about individual students' participation and learning, and successes and problems with the curriculum. These data were used to triangulate assumptions about students' roles in activity and learning throughout the unit.

Data analysis: reflection in classroom inquiry

In the theoretical framework above, we have examined what reflection in inquiry is; the contexts in which it can shape learning; and why it is important for making sense of complex data. In this section we examine the learning process for one student in the classroom, LaTanya (a pseudonym), using the conceptual framework to characterize change in three contexts. The case study shows the relationships among change in the three contexts:

- changing patterns of activity in the task context (guided participation in small-group interactions with complex datasets);
- students' development of reflective dispositions toward complex data over time in the role context (learning as participatory appropriation of roles); and
- students' development of conceptual understanding in the data context (apprenticeship to geo-scientific habits of mind, as represented in the curriculum design rationale).

David and LaTanya: the "Comfort Zone"

In order to look at an inquiry situation and try to make meaning of the complexity, a student must have a sense of comfort and confidence. Students often do not move beyond the point of awkwardness and discomfort in their roles as *inquirers*, particularly when it comes to problematizing things. Some students have enough will power and academic confidence to establish such a role on their own – they can jump into work with data and begin problematizing things, generating challenging questions and surprising observations, without much negotiation of this role with their fellow group members. But for many students, classroom inquiry situations begin with social negotiations of group norms and individual roles, which are a pre-requisite to problematizing anything.

This case study examines a group of two students, LaTanya and David, who established group norms which we have dubbed a "comfort zone" for work with data. Their group norms supported each of them in developing new roles in which they could work reflectively with complex data, in ways that they had not before. Their "comfort zone" mode of interaction mediated their mode of work with curriculum artifacts, promoting reflection in certain situations and inhibiting it in others. We will see how elements of

LaTanya's personality developed into a more reflective disposition through her engagement with the curriculum within this "comfort zone."

Who are LaTanya and David?

LaTanya and David had not been grouped together before this unit. Both were described by the teacher as "middle kids" academically, neither at the top nor the bottom of the class.

LaTanya is one of three African-American students in the class, all girls. One of the other African-American girls, Charlisse, is also a member of our focus table group; the other, Felicia, sits across the room. Both Charlisse and Felicia often approach LaTanya for social chats about life outside of school – who came over to whose house last night, etc. LaTanya frequently jokes and chats with other students, and seems to have casually friendly relationships with a lot of the students in the class. She laughs a lot, and is described by the teacher as having "a great sense of humor."

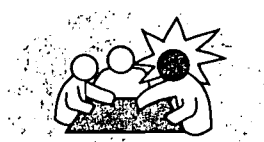
LaTanya's role in classroom activity early on: the "Frustrated Do-er"

LaTanya has many leadership qualities: outspokenness, communication skills, a sense of humor, and positive energy. She often pushes small group work forward toward completion, with comments like "Let's finish this up" and "OK, we done?" This tendency often seemed, in early work during the year, to move her group's work away from opportunities for reflection. In the words of the teacher, "LaTanya can be a leader ... but she also gives up too easily... [When there is something that is hard to figure out], she will laugh and let it go." [99-02-12] In other words, LaTanya did not tend to problematize much.

LaTanya's characteristic role early on can be described as the "Frustrated Do-er" – wanting to direct the action and move things along, but not engaging with the concepts underlying activity. Her "do-er" role is frustrated by problems with group dynamics – students not giving her the information she asks for, or a feeling that materials are not fairly distributed.

LaTanya's initial role:

"Frustrated do-er"



Student's role

- Focus on her role with respect to group norms (fairness issues)
- Wants to be central in completing task
- Focus on materials in defining task, but without connections to data context

In activities leading up to the Earth Structures unit, LaTanya's attention was often focused on the niceness or prettiness of things – wanting to make a nice poster, noticing which group has the more attractive map, mentioning how cool the letters look, comparing which picture is prettier. She enjoyed making things in class that looked cool, and her pride in her work usually focused on surface features of the materials unrelated to the underlying content of the task.

Focus Activity 1 provides a good illustration of this disposition. LaTanya was an active participant in group talk during Focus Activity 1, plotting current earthquakes. For example, during the first session of plotting, over a 20-minute period of group work, LaTanya contributed 56 of the table group's total 256 comments during discussion – which is 30% more than her proportional share of table talk in a group of six (i.e. with 256 comments in a group of six, each student's share of talk would be 43 comments).

So LaTanya was participating in group discussion – but what was she talking about? Many of her comments were about the materials used for the activity, such as the following:

> "Ooh yes, we get some stickers! Ooh, lemme see, David! Gimme some stickers! [chuckling] I should take one and put it on [me]!"
>
> *[pointing to other table]* "Awww, could we get that map? Their map is so much nicer!"
>
> "These [dots] are big"
>
> [98-10-26]

These comments suggest that she is focused on the materials, but is not connecting them with the task or the data (see Figure 5.8). Her comments are about surface features – how nice, how big.

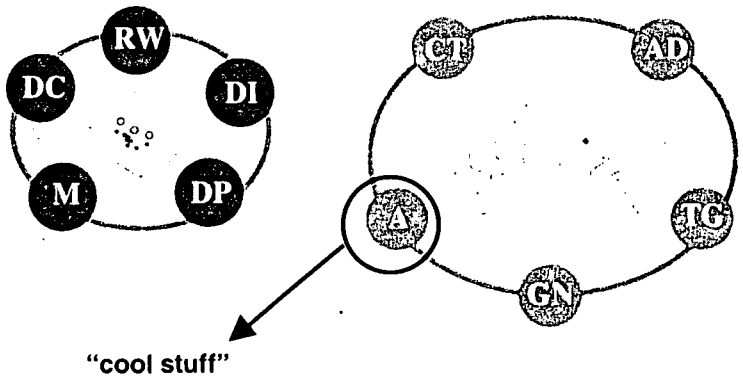


Figure 5.8. LaTanya focuses her attention on materials, but not in connection with the data context

Another focus of LaTanya's attention was trying to make sure she got her fair share in the group, and voicing frustration when she felt she didn't:

"Bring the map over here guys! Spread it out so everybody could see it."

"'Scuse me, could we get one more map, because they're like, so hogging it?"

"Now I put the freakin' dots on it, I don't care what you guys say"

[98-10-26]

Here LaTanya forcefully stakes out a role for herself in the activity, and demands equal time with the materials. But as far as interpreting the meaning of the task, and making sense of the data, LaTanya mainly relies on her group-mates to tell her what to do:

[motioning to area of map, asking David] "That's what we're doing?"

"What color [should I use]?"

"OK, point to Arkansas and pass me the thing that show what color"

"Man, could you guys tell me what color to use?"

[98-10-26]

In these interactions with the group, LaTanya does not problematize the data or the task for herself – she expects other students to provide the answers that require figuring things out. She has a relevant question about the materials: *What color dot to use?* But there is no "thing that show what color" – the students have not talked about the meaning of colors, and have no coding scheme. The question of what color to use became a focus of reflection for other groups in other classes, but here for LaTanya it is just a source of frustration – she asks her groupmates to tell her the answer, and they don't. LaTanya is focusing on the materials, her role, and the group norms in terms of fairness – but she

does not problematize the task for herself (only for her group-mates), and she does not connect with the data context (see Figure 5.9).

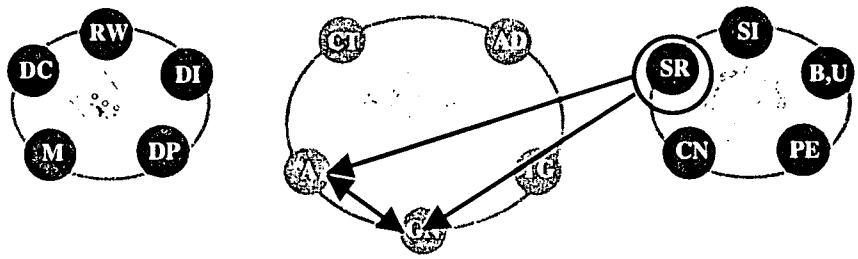


Figure 5.9. LaTanya's early participation avoided the data context, and did not problematize tasks.

This characterization of LaTanya's dispositions fits with the teacher's observations about her state of mind before the unit. In the teacher's words, "Where she was coming into [the Earth Structures unit], she was constantly arguing with other kids." At the time of the unit, "she needed to get past horrible experiences working with other kids." As far as engaging tasks and data only at the surface level, the teacher said,

> LaTanya was not very invested. She asks questions, but kind of just lets it go.. She knows what she wants to do, but she also gives up easy. She doesn't totally get in, she just kind of wades in the water.
>
> *[99-02-12]*

We will see how LaTanya's "wade in the water" disposition changed through the course of the unit.

Developing group norms with data: the "Comfort zone"

Through the activities of the Earth Structures unit, David and LaTanya worked out a shared space in which each could develop a more reflective disposition for making meaning of complex data. This process began in Focus Activity 2, Plate Mapping, when LaTanya and David became partners. Early on they negotiated a friendly mode of work together. In the example below, LaTanya right away demands her fair role in the task of drawing boundaries – showing her characteristic frustration – and David is responsive to her:

> LaTanya: Tokyo, we doin' Tokyo, Tokyo! ... OK, the plate boundary?
>
> David: Start like right here
>
> LaTanya: Let me do it some!
>
> David: OK, should I hold it down here?

[both draw lines] *[98-11-25]*

In the collaborative space created here, David becomes more verbal than usual, and LaTanya pursues her questions farther than usual:

LaTanya: OK, go ahead -- right here too -- plate boundary's right here, right?

David: This whole line is a plate boundary

LaTanya: Plate boundary's over here?

David: Just follow the black line

LaTanya: Plate boundary's over here too? ... Right here too?

David: See, cause this line represents all of this - all of this.. This would also be the plate boundary! {...} Then go down there ...

[98-11-25]

Here we see the two students coming to a nice balance of roles. LaTanya's high energy ("Tokyo, we doin Tokyo, Tokyo!") keeps their work moving forward, but does not push David into passivity. David's authoritative knowledge ("This whole line is a plate boundary") does not push LaTanya to the sidelines, but is shared and explained ("See, cause this line represents all of this"). LaTanya takes on a follower role to David regarding correctness of answers and understanding of the task, but she also puts forth her own answers tentatively ("Plate boundary's over here?") and shows a sense of ownership. In contrast to other groups we will see later, the decision-making space is shared comfortably.

These new norms afford reflection on the data context: LaTanya and David, for the first time in group work during the unit, are problematizing data patterns (lines of dots) and domain concepts (plate boundaries), as represented in Figure 5.10. LaTanya is talking about the task, and David is explaining his thinking.

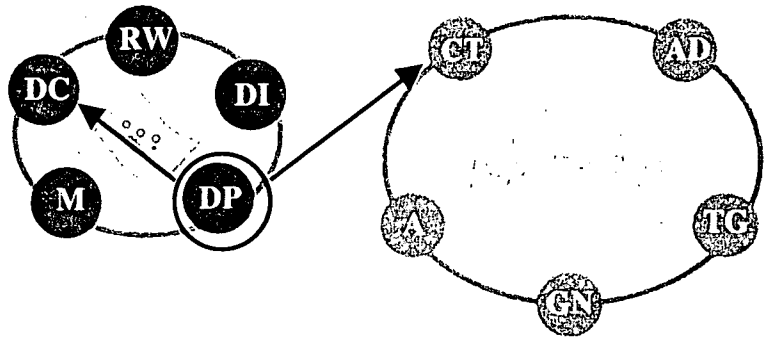


Figure 5.10. LaTanya and David bring elements of the data context into their discussion of the task.

Group norms:

"Comfort zone"

Group norms

- Mutual support
- Shared or jointly-developed conceptions of task
- Co-direction of work strategies
- Division of labor
- Joint, or uncontested, ownership of artifacts.

The "comfort zone" sustained reflection throughout the unit

This shared space was maintained by David and LaTanya throughout the rest of the unit. Here we see a smooth sharing of group talk and decision making during Focus Activity 3:

David: *[points to computer screen]* What is this?

LaTanya: What, this?

David: This whole thing. These islands. *[points]*

LaTanya: This, no ...

David: No, this I said. *[points]* Those are islands aren't they?

...

LaTanya: It's a subduction zone

[David types "subduction zone"]

[98-12-16]

Here we see both David and LaTanya jointly directing the decision-making in the work. They have maintained and improved their comfort zone since Focus Activity 2. Within this shared space, they are able to problematize different aspects of the inquiry situation.

David problematizes data points, identifying them as real-world items ("What is this?" ... "This whole thing. These islands"), and LaTanya recognizes a pattern, and makes the connection between the data pattern and a domain concept ("It's a subduction zone"). These connections are represented in Figure 5.11.

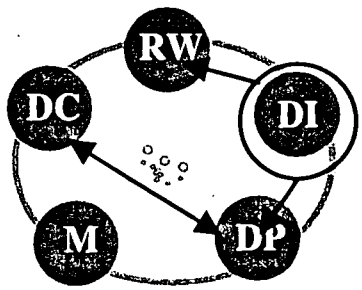


Figure 5.11. David and LaTanya jointly make connections among many elements of the data context.

In another episode, we can also see them working out a joint conception of the task:

David: *[points to text box]* That's where you tell the story.

LaTanya: No, you do the boundaries, you know ... He said do more than this.

David: Then do more.

LaTanya: David, where's the map? Go get it. I need to know what is that around there. *[points to part of clay model in picture]* I need to go back, to our other thing with the [earthquake data]

[David finds that page and displays it]

LaTanya: OK, where's our plate? Is this our plate? *[points]*

David: *[circles with finger]* This is our plate all around there.

[98-12-16]

Here they problematize the task and their strategies for doing it – what are we supposed to do on this page, in this space? Should we put more there? (task ←→ strategies) LaTanya raises the need for more data – problematizing the task in connection with a model of their plate, and realizing she needs other materials ("David, where's the map?"). David gets the data for her; she problematizes the data patterns by questioning how they relate to a domain concept ("OK, where's our plate at?"); and David provides his interpretation of the data ("This is our plate all around there"). In a comfortable flow of activity, the relationships among data, models, and concepts are explored, and they discuss how to complete their inquiry task (Figure 5.12).

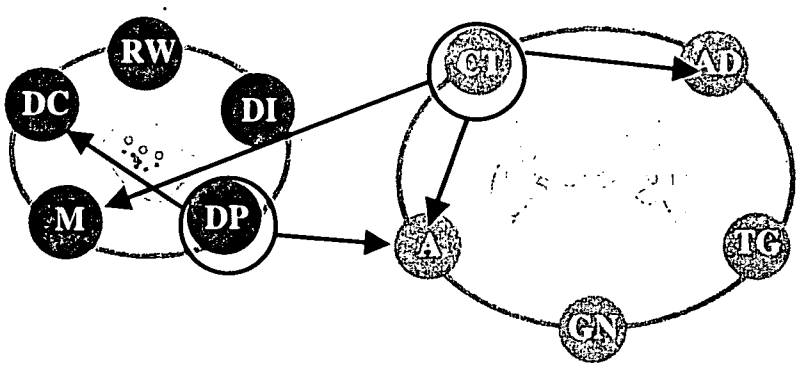


Figure 5.12. LaTanya and David fluidly make meaning of their task and large amounts of data.

These kinds of "comfort zone" reflective episodes for David and LaTanya are found all the way through the final day of the unit. As we will see later, this comfortable shared space is not the only kind of reflective work mode which students created in this unit – others were less harmonious, though no less reflective. But this "comfort zone" worked well for these two students: it afforded LaTanya and David opportunities to reflect together on inquiry situations with complex data, in ways that they had not done before.

The comfort zone has trouble with uncertainty

A major challenge for this group in working with data in this comfort zone was figuring out how to make room in their conversations for *uncertainty* about the inquiry. Resolving this challenge shaped the kinds of reflections that happened in LaTanya and David's investigation. They needed to get past the urge to find a quick and easy answer, in order to make the complex data problematic. This presented a different challenge for each of them. David needed to get past his tendency to do his work quietly and alone, and his tendency to lapse into goofiness when working with others. We have seen that he was willing to grapple with difficult ideas, but not in a group. LaTanya needed to get past her focus on surface features, and her desire to finish quickly. She needed to be willing to work past her frustration in confusing situations.

During Focus Activity 2, students were to draw their plate boundary predictions, using a big set of data on a map. The data map was created with the intent of making this task an uncertain one, requiring students to debate their lines (see Design Rationale secton above). In a conversation with Mario, David confronts a confusing area of the data map:

David: *[to Mario]* This would be a plate boundary! Look, this all could be a plate boundary!

...

Mario: *[pointing to an area without dots]* What the heck is this? Is this the bottomless pit or something?

David: I know! There's like nothing here!

Mario: Right here it's a bottomless pit!

David: Put a question mark! *[laughs]*

Mario: *[joking tone]* "They say no one has ever lived here.."

[98-11-25]

Here Mario problematizes the data pattern, and David is able to join him – he combines his tendency to joke with the discussion of the data. He has benefited from Mario's observation, and made it his own. (We will see later that Mario had benefited earlier from Joel's observations in the same way.) David and Mario proceed to share their observation of this "bottomless pit" area with Juan, who then writes on the map overlay, "What is this?" – pointing to the bottomless pit. They are proceeding with the task as it was designed: problematizing uncertain data patterns for further investigation.

But LaTanya becomes upset with Juan for writing on her plastic overlay. She does not so easily make room for uncertainty in the data – she is more concerned about somebody interfering with her materials, "messing up" her plastic:

LaTanya: *[to Juan, angrily]* Why, why did you write that for? What do you mean, 'What is this'?

David makes an uncharacteristic move at this point – rather than laughing at the conflict, as we would have expected earlier, he steps in to explain the data pattern to LaTanya:

David: Cause look, there's all these earthquakes around here, and then there's nothing here

...

LaTanya: *[pointing to another area of map]* So? There's nothing here either! ... Tokyo, Tokyo - OK, we're about done, right?

LaTanya does not gain interest in the pattern, as the other three have. She explains it away ("So? There's nothing here either!"). She is not interested in talking about the "bottomless pit" or what it might mean. She then proceeds to try to bring the activity to closure as quickly as possible ("OK, we're about done, right?"), ending the discussion of the strange data pattern.

LaTanya's lack of interest in uncertain data is something we had expected from students, and tried to design for. To promote a sense of the validity of uncertainty (i.e. "it's OK to not have a definite answer"), we designed one part of the plate-mapping activity (Focus

Activity 2) in which students mark their plate lines in two colors – one for "Sure" and one for "Not sure." Then, in mini-conferences between small groups, students are to report their sure and unsure boundaries to each other, compare their lines, and discuss where more data is needed.

Neither David nor LaTanya engage productively with the "Sure – Not sure" activity and the mini-conferences. LaTanya at first shows no interest in participating in this activity ("I'm not gonna say nothing in my presentation!"), but as David begins to present their plate, she decides to jump in ("Oh, now I have to do it with you ... this is what I'm gonna say").

However, after explaining the "sure" boundaries, she then turns to David to show the "not sure" areas – a concept that she is still not comfortable with – but David also refuses to characterize any lines as "Not sure":

LaTanya: OK, this is where Tokyo is ... The name of our plate is Azmina. And then - this is where we're all sure of *[pointing]* - and then now David - you're gonna show where we're not sure of - and then you show the, uhm -

David: We're sure of them!

LaTanya: *[throws down pencil]* Why, then, you say it!

[98-12-03]

LaTanya has lapsed into her mode of frustration with group-mates, and David has retreated from the idea that some of their lines are not sure ("We're sure of them!"). He then lapses into his sarcastic mode of group interaction, when Ben tries to question his data interpretation:

Ben: One thing I'm confused of, *[pointing to SE area of plate]* how come there's//

David: //Because there's ... *[adjusts loose pages of map]* ... when we did this they weren't even taped on. So that's why it seems to be - fucked up!

...

David: Luckily Tokyo was in the middle of a bunch of earthquakes, ... we go up - and go down, and around, and etcetera, etcetera, etcetera *[pointing playfully around the plate]*

[98-12-03]

David and LaTanya both become frustrated with the activity – LaTanya because of her discomfort with her share of the task, David because of frustration over materials. The

intended effect of validating "Not sure" interpretations did not happen for this group. Other students (Ben being one example) took to making these "Sure" and "Not sure" lines enthusiastically, but David and LaTanya never became comfortable with this activity.

Validating differences of interpretation

A big step for David and LaTanya in embracing the uncertainty of data analysis came through a problem they faced twice as a group: having different interpretations of the data, or different "answers" to the data-analysis question. The first divergence came during the plate-mapping activity (Focus Activity 2) – here a researcher asks them to explain where they think the plate boundaries are:

David: I think that I know - cause look, there's all these earthquakes around here, so this could be one plate, and where like none, it probably ends. And like right here, there's probably one starting all over again {...}

SM: OK. So you're predicting possibly two plates in this area? And what would you say, LaTanya?

LaTanya: One big one.

...

LaTanya: Cause there's a lotta earthquakes. And so, and then it stops right here, so maybe there's a plate right here, over there.

David: No, I'm thinking like, this is where the plate ENDS, cause there's none right here, but then they all start all over again. *[98-11-25]*

They have different interpretations of data patterns, and as a result they do not know how to proceed with the task. Their group norms do not allow for debating their different strategies or interpretations. This is an awkward moment for their group, as they do not know how to work together when they disagree. LaTanya and David are not sure how to proceed, given that they do not agree on their plate outline.

Later, the teacher comes over to meet with them, and David raises their disagreement with her as a problem:

Teacher: *[to David and LaTanya]* Where do you think the plate is?

...

David: ... I think, I think there's two plates over here, around here, but LaTanya thinks it's all one.

Teacher: OK. OK, well that's something we'll have to {work out} later ...

David: I think that this, right here, is all a plate *[big area in the Pacific]*, but since right here there's like nothing, except for like a few, and I think that this starts a new plate.

[98-11-25]

By the end of the period, we see two different attitudes these two students are taking toward their difference of opinion. LaTanya settles on the stance that they each have their own idea – in fact, each their own plate – achieving a kind of closure on the question, and avoiding dealing with uncertainty:

LaTanya: There's Tokyo - and we named our two plates ... *[pointing to line]* David plate's right there - there go my plate

LaTanya has put the problematic data into a convenient box – "our two plates" – rather than problematize either of their interpretations. David, however, leaves the "correct" answer as an open question:

David: Well, we're not sure yet, cause we have to add these *[extra data pages]*

David places the burden of resolving the uncertainty on their problems with the materials – they need to add more data pages in order to figure out the right line.

Help from the teacher: Validating different interpretations

The second divergence of their interpretations comes during Focus Activity 3, when they have to decide which way their plate is moving. The teacher again comes in to help them mediate a difference of opinion, and helps them make their interpretations concrete in the form of separate Data Interpretation pages in the Progress Portfolio:

Teacher: So do you agree David? Or do you want to do something else? Do you want to make a different prediction?

David: There's only one thing, like, cause I disagree on the plate motion.

Teacher: *[to LaTanya]* OK, is your plate motion labeled on here?

LaTanya: Yes.

Teacher: OK, prediction of motion. Let's do the same all over again, but for David's now.

[Teacher captures the clay plate picture into their Portfolio and makes a separate page for David]

Teacher: *[to David]* So then you just have to explain what direction you think it moves in. OK. And then we'll call this ... "David's predictions of motion." So then you can put your predictions.

Here the teacher validates the idea that the data can support different interpretations, and encourages them to explain their different positions within their work product. This intervention is a very effective repair to the breakdown in this group's "comfort zone dynamics (see Figure 5.13), and enables them to continue with their inquiry project.

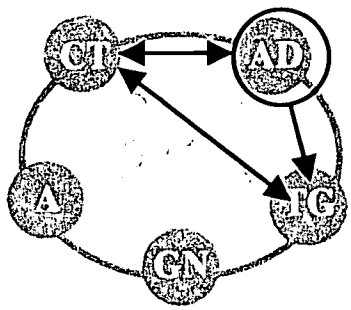


Figure 5.13. The teacher's modeling of how to present separate interpretations re-establishes this group's "comfort zone" mode of activity.

This permission to disagree helps David and LaTanya maintain their comfort zone – they do not have to argue about who is right, but can keep both of their interpretations within their project. They maintain separate "David's prediction" and "LaTanya's prediction" pages right through the final presentation.

This resolution of a disagreement highlights both a strength and a weakness of the "comfort zone" for work with data. Maintaining separate interpretations of the data enables David and LaTanya to stay within their comfortable space for inquiry discussion, avoiding a potential conflict. On the other hand, it does not allow them to push their investigation to the next level of reflective consideration – i.e. comparing the two predictions to see which is better supported by the available data, or arguing their positions using evidence. This would likely have pushed David and LaTanya out of the comfort zone, either making LaTanya mad or making David withdraw. However, had they done so, they might have found a major oversight in David's boundary line, and could have developed a more coherent analysis of how their plate moves.

Preparing a final presentation: Reflection on models, avoidance of data

The activities with data were designed to give students a wide range of representations of data and concepts, in order to help them build connections. However, different students

found particular representations more useful than others as objects of reflection. For a variety of reasons, David and LaTanya both spent more time problematizing models and concepts than data points and data patterns.

For LaTanya, the models that they created – their plate map, the clay model of Japan, and the clay model of their plate – seemed to be highly-valued artifacts of the inquiry. Many of LaTanya's reflections occurred while she was looking at a photograph of her clay plate model in the Progress Portfolio. These model-making activities tapped into LaTanya's pride in creating nice-looking things in the classroom, as we see in comments like this:

LaTanya: *[showing plate model]* It took me three days to do this!

[98-12-03]

LaTanya: How did you guys name y'all's plate? ... Look what I named ours ... Azmina.

Shami: Who's Azmina?

LaTanya: My cousin

Shami: Why'd you name it Azmina?

LaTanya: Cause she's pretty

[98-12-03]

LaTanya: Go to 'LaTanya's clay model.' That's what I did.

[98-12-16]

At times LaTanya's affection for these models got in the way of problematizing the data and concepts which they were made to explain. For example, she spent time and concentration on deciding the right name for her plate, but this ended up being time taken away from figuring out the data (see Figure 5.14). However, these non-data-context connections with classroom artifacts also provided valuable connections for LaTanya between the task context and her non-school identities in the role context.

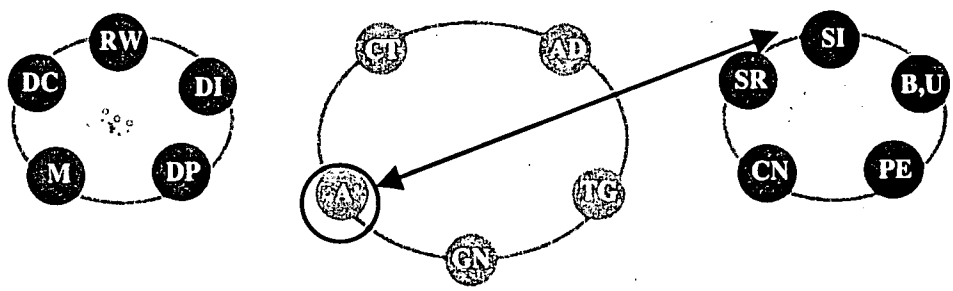


Figure 5.14. LaTanya connected classroom artifacts with her non-school identity.

However, this identification with the material products of activity also could serve as a lever for promoting reflection in the task context and the data context:

"So something's going on down here. On my clay model, yes it is!"

[98-12-17]

In this way models often served as an anchor for her in thinking about the concepts, as they were intended to do. LaTanya's personal-life connections and her data-context connections to artifacts were not incompatible. We will return to this theme below.

For David, the domain concepts explained by the teacher in mini-lessons – such as the concepts of subduction zone, buckling zone, etc – became a main focus of his thinking toward the end of the unit. He often used the hand-motion models of each type of plate boundary zone to describe them, and he spent much of his time in the Progress Portfolio writing down what these zone types were. David and LaTanya together spent a good deal of time writing concept definitions from David's journal into their Progress Portfolio file.

For David and LaTanya as a group, reflections about models and domain concepts often pulled them away from problematizing the data they had been studying. For example, in preparing their final presentation (Focus Activity 4), they left out many of the reflective observations about the data they had made up to that point, and focused primarily on defining and demonstrating domain concepts. In other words, the Presentation Preparation activity failed to prompt reflection to the data patterns explored earlier.

In an extended episode from Focus Activity 4, shown in Table 5, we can see how reflections on data during Presentation Preparation were avoided by this group, even when prompted. This takes place after David and LaTanya have spent a long time typing in definitions of the zone types from David's science journal into the Progress Portfolio. Their presentation contains little explicit discussion of data patterns. The researcher (JR) comes over to prompt them to use data in their discussion, suggesting that they use a particular strategy: connect their zone definitions with data images from their plate investigation.

Table 5: LaTanya and David avoid explaining data in their final presentation

Student discourse	Strategy for task
LaTanya: *[reading]* "Another is a buckling zone"	*DEFINING DOMAIN CONCEPTS*
David: "Another is a buckling zone. That is when –" *[typing]*	"
LaTanya: This presentation better be done by today!	*FOCUS ON FINISHING*

... *[looking at instructions]* Let me see, we need detail, effort - Details! Lots of details!	
David: No!	
LaTanya: Yes, details	
JR (researcher): *[coming over]* Yes! What details?	*PROMPT TO REFLECT ON TASK*
David: *[chuckles]* I don't know!	
LaTanya: We have details about each zone - *[to David]* keep typing, you keep typing	
JR: Can you show an example of each zone?	*STRATEGY SUGGESTION – USE EXAMPLES FROM DATA*
LaTanya: We don't —	
David: We didn't show - you mean, write it down, or --?	*DEFINING CONCEPTS*
LaTanya: No, pictures!	*UNDERSTANDS SUGGESTED STRATEGY*
David: Yeah, we're thinking like, we can pick up the model and show it *[gesturing with hands]*	*USING MODELS FOR DEFINING CONCEPTS*
JR: Or, what about when you're on the computer, since you're there now - what can you show - what details could you show to explain what you're talking about? Pretend you're a 10-year-old kid, and you're sitting there listening - and you said, a buckling zone is what?	*PROMPT TO REFLECT ON PRESENTATION TASK*
David: When two continental plates collide//	*DEFINING CONCEPTS*
LaTanya: //and it forms a mountain// *[hand gesture]*	*USING MODELS FOR DEFINING CONCEPTS*
David: *[hand gesture]* //and they buckle up and forms a mountain	"
JR: OK. Can you help me understand that by showing me a picture of one? Do you have one in there anywhere?	*PROMPT TO USE DATA*
David: No	
JR: No?	
LaTanya: Not in this	*AWARENESS OF THE DATA*

JR:	Which zones do you have examples of on your plate?	
LaTanya:	So far? Oh, on our plate? Subduction zone	*CONNECTS DATA TO CONCEPTS*
JR:	Can you show a subduction zone?	*PROMPT TO EXPLAIN DATA*
LaTanya:	Oh yeah, I could show you a subduction zone. *[opens a page with lots of earthquake data displayed]* That's a subduction zone, and that's a subduction zone, and like that ...	*CONNECTS DATA TO CONCEPTS*
JR:	That's the kind of detail you want to have	*CONFIRMS STRATEGY*
LaTanya:	OK	
David:	And then we need like - I don't think we have any buckling zone on our plate. *[opens another page]*	*CONSIDERING STRATEGY*
LaTanya:	What is it, just include everything that we have on ours - before we run out of time? *[pointing to clock]*	*FOCUS AGAIN ON FINISHING*
[teacher reminds the class that they need to have both a compter presentation and a physical presentation]		
LaTanya:	Oh my gosh David! Physical! What are we gonna do!	*FOCUS ON FINISHING*
David:	Physical, we just tell the story ...	
LaTanya:	Don't we need some pictures ...	

[99-01-12]

This discussion shows some productive reflections when they are prompted: LaTanya identifies a series of subduction zones from data, and David notices that there are no buckling zones on their plate. They seem poised now to gather "some pictures" – data images showing the boundary zones around their plate.

But they do not sustain this mode of reflection on data – when they realize they are running short on time, they stop looking over their data collections, and focus instead on a lengthy process of creating large paper models to demonstrate how a subduction zone is formed. Both of them start excitedly discussing how they could make cool paper models showing how mountains appear near plate boundaries.

These kinds of discussions did provide opportunities for reflection among three elements of the inquiry situation: models, domain concepts, and real-world items (see Figure

5.15). However, by missing opportunities to connect these with data points or data patterns, they missed some opportunities to build stronger connections in their domain understandings. Their final presentation focused much more on *explaining* domain concepts, than on illustrating these concepts by showing their *observations* from data.

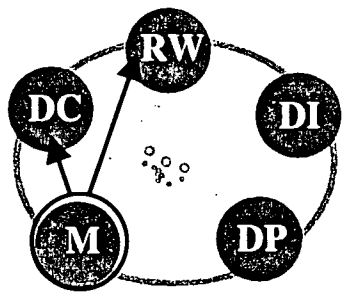


Figure 5.15. David and LaTanya's focus on models in Activity 4 connected to concepts, not data.

It is worth noting that their avoidance of more data analysis in this final Focus Activity may have been partly due to classroom logistics. Both LaTanya and David had several absences during the final weeks of the unit, and they were only together in class for one day of the intensive computer work with data during Focus Activity 3. Had they had more time to collect data, they might have featured it more prominently in their presentation, and spent more time reflecting on it in their presentation preparation time.

Summary: the "comfort zone" norm of group activity

The case study this far has focused on the development of group norms within the task context. We have seen how this group established a "comfort zone" for working together in activities with big data sets, adopting complementary roles. We have seen their difficulties making sense of tasks in which answers were uncertain, and we have seen how the teacher guided them in dealing with multiple interpretations of data. We have also seen how they settled into a comfortable mode of reflecting on unambiguous models and concept definitions, avoiding some of the more problematic discussions of data.

Learning outcomes: Changes in roles, dispositions and understandings

Now we turn our attention from the development of group norms on the plane of guided participation (the task context), to evidence of individual learning and change on the plane of participatory appropriation (the role context). So what did LaTanya learn during this inquiry unit? What understandings, abilities, and dispositions toward data did she

come away with? What was appropriated from the patterns of social activity we have discussed so far?

To answer these questions we can examine both the reflective episodes during the unit, and the understandings each of them showed in individual interviews after the unit.

LaTanya's emerging disposition to problematize data and concepts

One change during the unit was LaTanya's visible development of a disposition to problematize data, models, and concepts. She moved from a focus on surface features of the materials, and a disposition to finish activities as quickly as possible, to a sustained interest in figuring out confusing aspects of the investigation.

In Focus Activity 2, LaTanya showed a tentative interest in explaining her observations, but she was still grappling with the words, the concepts, and their relation to the data:

SM (researcher): And where do you think the boundaries of the [plate] might be?

LaTanya: The plate boundaries? Where do you think the edges of it - the boundaries?

SM: Yeah - which would be like the edges of it.

LaTanya: Maybe - maybe *[pointing]* - hold on, I gotta think about it for a minute. Maybe right here - somewhere?

SM: Uh-huh - and why are you thinking that?

LaTanya: Cause it's a lotta, there's a lotta, there's a lotta what does these dots stand for again?

David: Earthquakes

LaTanya: Cause there's a lotta earthquakes. And so, and then it stops right here, so maybe there's a plate right here, over there.

[98-11-25]

Here we see she is still uncertain about the relation of data points to their referents ("what does these dots stand for again?"), but she is beginning to generate tentative explanations for data observations (see Figure 5.16).

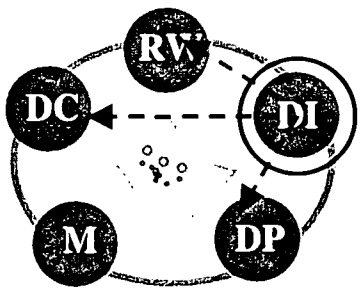


Figure 5.16. LaTanya's tentative connections in the data context in Focus Activity 2.

By Focus Activity 3, LaTanya shows a more confident and adept approach to relating data to concepts. LaTanya contributes her understanding of subduction zones to a whole-class discussion, relating data patterns to domain concepts:

Teacher: So what kinds of zones ... how do you know they're subduction zones?

LaTanya: Cause they're a nice line of volcanoes

[98-12-11]

This is the first time LaTanya has answered a "data-context" question during whole-class discussion, and suggests a new level of confidence in her understandings.

LaTanya's change in understanding and confience was accompanied by a change in her disposition toward tasks. In group-work toward the end of the unit, LaTanya is very focused on the work of documenting the motion of their plate She no longer shows her earlier desire to finish activities as quickly as possible:

LaTanya: ... subduction zones .. We gotta get some more of these! ... Hawaii's right there - hmmm - Come on, I want to go to some of these. Where's our plate at? Is this our plate under here? Oh, this is it. Oh yeah, we gotta name the motion of the plate?

...

David: Alright, that's enough

LaTanya: No, we gotta know what's down there

David: ... Why?

LaTanya: Hey go to that big world map

[98-12-17]

Here David pushes for quick closure ("Alright, that's enough"), but LaTanya wants the explanation to be complete, rather than just finished ("No, we gotta know what's down

there"). This is a marked change from her earlier disposition to finish as quickly as possible. She has problematized the task of explaining the processes going on on her plate, in a way that was rare for her earlier in the unit. She connects it with materials and strategies ("go to that big world map"), in addition to the underlying meanings in the data context (Figure 5.17).

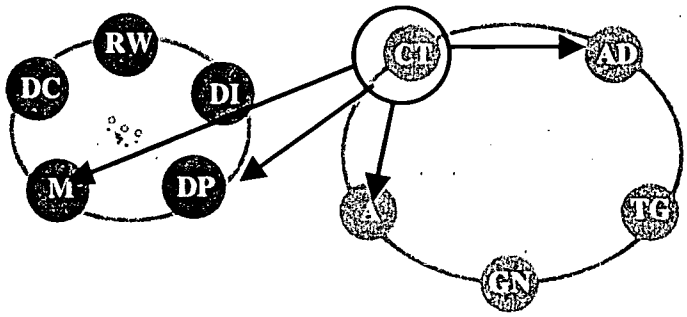


Figure 5.17. LaTanya's more reflective engagement of tasks.

Within the data context, LaTanya problematizes patterns of data which are not easy to explain. She also seems very confident in her ability to figure out this confusing area:

> LaTanya: *[making an earthquake data query in the software]* hold on, hold on - cause these dots are pretty small *[chooses a larger dot size and displays data]* ... So something's going on down here. On my clay model, yes it is! Concentrate David!
>
> ...
>
> LaTanya: What's going on down here? It's a lot of volcanoes ... I wanna find out everything. Subduction zone, subduction zone, subduction zone ...
>
> *[98-12-17]*

In these few reflective comments, LaTanya shows that she is problematizing not only the task, but also several elements of the data context, making many connections:

- a real-world place ("Hawaii's right there"), with reference to data patterns ("I want to go to some of these") and domain concepts ("where's our plate at?");
- a data representation ("these dots are pretty small"), with reference to a data pattern she wants to be able to see;
- a data pattern ("something's going on down here"), with reference to a model of her plate prediction;

- a different data pattern ("It's a lot of volcanoes"), with reference to a domain concept ("subduction zone, subduction zone, subduction zone").

The reflective connections LaTanya makes in this brief period represent a significant tying together of perspectives within the inquiry situation.

But a reflective disposition did not replace her other dispositions

But it is important to understand that LaTanya's development of a more reflective disposition in this unit did not *replace* her earlier dispositions – rather, it developed out of them. Throughout the unit she maintained her focus on an attractive surface appearance of the artifacts of inquiry. Even in the final presentation she spent a good deal of computer time changing the font size and type style of the letters ("I want everything to be in STYLE!"). However, whereas earlier this focus was completely apart from the substance of the investigation, LaTanya's focus on style merged with her process of interpreting data.

For example, during the plate mapping activity, LaTanya became concerned about the lines they were drawing on plastic becoming too "sloppy" or "junky":

LaTanya: OK, I got some 409 [to erase with]. I drew the line too thick. OK, write it over

[98-11-25]

This concern matches with LaTanya's focus on surface appearances, but it also becomes important to the data analysis they are doing. Too thick of a line over-simplifies the decision of where to draw the line – it also obscures the important distinction of which things are on which side of the plate boundary. In effect, sloppy lines serve to de-problematize the task. LaTanya recognizes this problem during a discussion between their table group and the teacher, whereas David and Mario do not:

Teacher: I'm not sure, I'm not convinced. Cause I look like, this mark [Tokyo] is more on THIS side of this line, and Honolulu's on THAT side of that line

LaTanya: *[erasing with towel]* Let's make it clearer.

David: But look over here//

Mario: //I think it probably would go in there *[points to Asia]*

Teacher: So maybe there's a plate line this way.

LaTanya: Look at all this marker

...

David: //I think it MIGHT be going this way! *[points to Asia]*

Teacher: I don't know. I think maybe you need to know where Tokyo is more specifically, though.

LaTanya: Yeah, cause this [Tokyo dot] is like a big old -

[98-11-25]

LaTanya grasps the teacher's point – that they cannot interpret which plate Tokyo is on until their markings are more clear. Her concern for clear lines and neat dots in the plate mapping activity comes up again the following week, during a mini-conference:

Ben: Do you agree with us?

LaTanya: About what!?

Ben: Our plate boundaries

LaTanya: You know what I think, I think y'all should erase some of this and make your lines very clear so I could see -

David: We're not sposed to erase em

Ben: We can't erase them

[Ben traces again around plate with marker]

LaTanya: See you making too many lines!

Ben: This is the line, all the way from here -

LaTanya: That's too many lines, I'm not paying attention

Ashish: That's around Africa, isn't it? Around Africa and the mmmm-Middle East? ... whatever?

LaTanya: Ha ha, I know man, this an ocean ... *[points to Atlantic part of plate]* this side here - I don't know what y'all did! ... You know what I don't get? You guys have too many lines ... too junky.

[98-12-03]

Here it is clear that she is questioning the other group's work not just based on style, but also on its value as a model to represent the relation of the plate to the Atlantic Ocean (see Figure 5.18). LaTanya is absolutely right in her critique of the other group's plate lines – they are too sloppy to be useful when they later have to determine which kinds of boundary zones they are.

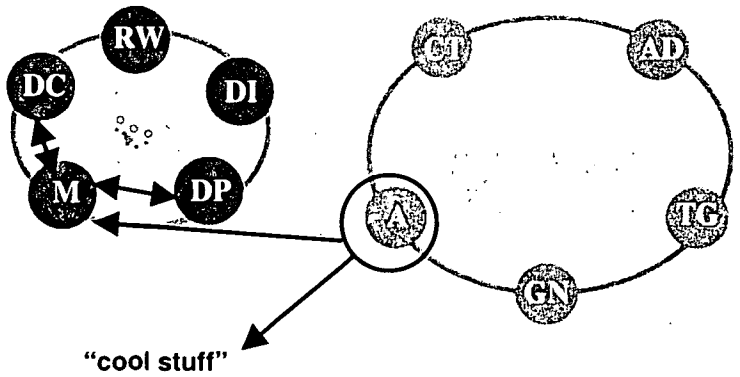


Figure 5.18. LaTanya problematizes the sloppy plate model within AND outside of the data context.

This shows how a more reflective disposition in interpreting data does not have to *replace* students' current dispositions, but can build on them. LaTanya's concern for neatness becomes what Dewey might have called a "native resource" for reflectiveness in her personality – one that can be developed through inquiry experiences from a content-free concern with appearances, to a productive habit of accurate representation.

Also, different dispositions toward data co-exist at the same time. We have seen earlier how David and LaTanya steered away from problematizing data in Focus Activity 4 (Presentation Preparation), after having done the kind of reflective work we have seen above in Focus Activity 3. This should not be surprising – research has shown more- and less-adaptive reasoning strategies co-existing for long periods of time (Kuhn 1993).

Changes in LaTanya's domain understandings

What did this more reflective disposition help LaTanya to learn? She showed an ability to draw on many of the experiences and concepts to explain things in the world in the post –interview.

JR:	*Do you think that the ocean floor is the same everywhere, or do you think that it's deeper in some places and shallower in other places?*
LaTanya:	I think it's probably shallower in some other places
JR:	*Where do you think it would be shallow and where do you think it would be deep?*
LaTanya:	It would be deep in here - right down South America right here *[points to map]*
JR:	*And how do you know it would be deep right there?*

LaTanya: Cause remember when we were doing the computer, and this is a trench? And a trench means like it's deeper, so the water probably WOULD be deeper. And you could see those lines of dark blue and light blue. *[pointing to topographic lines on map]*

Here LaTanya reflects on prior experiences ("remember when we were doing the computer?"), data on a map ("you could see those lines of dark blue and light blue"), and domain concepts from the unit ("a trench means like it's deeper"). She uses the connections among these to find a place where the ocean would be deep, and to explain her observation. However, she is less sure of herself in trying to explain a mechanism:

JR: *What might cause it to be deep or shallow?*

LaTanya: I don't know, maybe it's because of, uh -- maybe because of the plates?

JR: *OK, so how would that work - how would that make it deep?*

LaTanya: Cause me and David did our plate - right on here and then over -- *[showing near and far sides of map]*

...

JR: *So how might the plate make it deep?*

LaTanya: It's like, here, I don't know what happened to make it deep *[looking closely around South America]*

JR: *OK, take a guess*

LaTanya: Cause it's a trench? It's a trench right here, and a trench means it's very deep - so maybe the water became deep along the coast. *[pointing]*

LaTanya is tentative, seeming first to guess ("maybe because of the plates?"), then fishing for a connection to her work with David ("Cause me and David did our plate"). She does not connect to the concept of subduction zones to explain how a trench is formed, despite the fact that this process was featured prominently in her own final presentation. These connections are still tentative for LaTanya, although many of the conceptual pieces and data analysis abilities are there.

LaTanya's reflective disposition in reasoning from data is evident later in the interview, when she is asked to predict where on a world map we might expect to find volcanoes:

JR: *Where would you predict volcanoes might erupt, on this map?*

LaTanya: Right - volcanoes - they'd be right here. *[points]*

JR: *OK, ... anyplace else? Or is that the only place?*

LaTanya: Uh-uh. Volcanoes -- in here too - in, um Europe.

JR: *OK, why do you think there'll be volcanoes here?*

LaTanya: Because, I'll show you on this picture *[turns to big wall map]* - there's a trench too, on this picture, and it has deeper water right here, like in that other graph that you showed me - and, since it's two plates, it crashes into each other, and there's volcanoes.

JR: *OK ... And why do you think there might be volcanoes right here?*

LaTanya: Because, in - the last time you showed me this, you showed me another picture, with a lot of red dots for the volcanoes. And plus Russia has, like a lot of mountains, see all those mountains right there? *[points to wall map]* And it has a plate under it, and the plate has, Indian Ocean, too, and they each crash into each other, they form a mountain. Oh right, it's some right here too *[points to another place on map]* - volcanoes.

JR: *Why do you think ... here in the ocean?*

LaTanya: Because it's the two plates - it's like, it's a continent? You can just picture like this going under the continent, and then you have Atlantic Ocean *[pointing]*, which, they both have plates on 'em. So they crash into each other, and move into each other, they form a volcano in the ocean.

Here LaTanya uses several sources of information flexibly:

- information from two different maps ("on this picture ... like in that other graph");
- her memory of a data map ("you showed me another picture, with a lot of red dots for the volcanoes");
- knowledge of places in the world ("Russia has, like a lot of mountains", "Atlantic ocean");
- domain concepts from the unit (trench, plate); and
- a detailed mental model of plate motion ("You can just picture like this going under the continent").

This explanation of her prediction of where volcanoes occur shows a complex web of reflective connections LaTanya has made, using all five elements from the data context to explain her prediction (Figure 5.19).

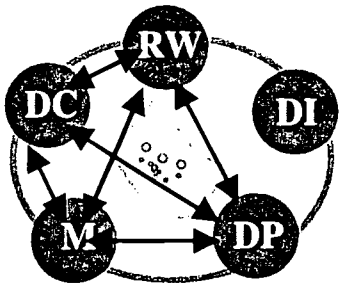


Figure 5.19. LaTanya makes many data context connections in explaining where volcanoes happen.

It also shows gaps in her learning – she uses a description of *subduction* (one plate going under another) to describe areas that are formed by different kinds of plate motion (buckling in India; rifting in the Atlantic Ocean). LaTanya and David focused mainly on explaining subduction in their presentation, and identified only subduction zones on their plate – and so she over-generalizes her knowledge of this zone to explain other data. However, she has clearly developed a very detailed schema about earth structures and processes which could be improved by future learning.

Summary

We have seen how two students established a set of norms of group work in data-rich inquiry with distinct characteristics:

- mutual support;
- frequently shared or jointly-developed conceptions of the task;
- co-direction of work strategies;
- division of labor; and
- joint, or uncontested, ownership of artifacts.

We have named this set of norms the "comfort zone," to suggest the supportive environment it created for these students.

We have seen that these norms afforded certain opportunities for reflection on complex data, especially through discussion of relationships between models and concepts, and reciprocal questioning and answering. We have also seen that these norms constrained certain opportunities for reflection in the data context, especially in cases of uncertainty and disagreement.

We have seen how LaTanya came to this group process with certain dispositions (evident in prior and early-on roles) which had kept them at the periphery of active engagement of data, and thus had constrained opportunities for reflection. She was a "Frustrated do-er" who tended to engage materials without engaging the data context of activity. We have seen how she developed new roles within and through their joint development of "comfort zone" norms. She became more of a "Questioner" – more disposed to link inquiry artifacts to their data-context referents, and more disposed to problematize tasks beyond their surface features.

We have also seen that LaTanya developed new habits (in the task context) and new understandings of earth science (in the data context) that fit our model of reflection. That is, they both showed an increased ability and tendency to problematize elements of an inquiry situation, and establish connections with other elements of the task and data context to make meaning of them.

Finally, we have seen that this student's more-reflective roles and dispositions developed out of their identities and prior roles, rather than replacing them. Less-reflective and reflection-neutral dispositions did not disappear. Instead, these other aspects of identity and role (e.g. LaTanya's focus on materials products of her work) provided the basis for their development of more reflective roles and dispositions.

Discussion

The goal of this analysis has been to better understand the processes of becoming more reflective, and learning through reflection in inquiry activity. I have attempted to show how social interaction and conceptual understanding can be represented within a common framework, rather than separately as causes and effects.

The analysis leads us to five claims about learning to reflect in inquiry with complex datasets:

Claim 1: The sense that is made of activity mediates the sense that is made of data

Claim 2: Reflective inquiry dispositions develop out of inquiry-irrelevant dispositions

Claim 3: Content learning and group interaction modes are interdependent

Claim 4: Reflection in inquiry is a shared, social process

Claim 5: Participation and interaction modes are sites of inquiry learning

These claims arise out of the data analysis, and they both inform and are informed by the theoretical framework developed above in Section 2.

How do students learn to make sense of complex information through classroom inquiry?

Claim 1: The sense that is made of activity mediates the sense that is made of data

We have seen that students learn to make sense of complex information as part of the larger process of making sense of activity. The sense that is made of activity mediates the sense that is made of data. Classroom inquiry tasks are given meaning by participants in activity, rather than by curriculum designers or teachers alone. The relationship between students' emergent interpretations and the meanings intended by curriculum designers and teachers is problematic – it should be determined through study rather than assumed. We have seen students make sense of data in both domain-relevant and domain-irrelevant ways, and we have seen students develop increasingly-relevant conceptions of data and tasks under certain circumstances.

The process of learning to make sense of complex data has been shown to be a process of changing the ways that sense is made of activity, rather than making sense where none was made before. Every classroom interaction involves making sense, and the goal of instruction is to develop a coherent set of conceptual referents with which to reason about

data – a data context. Viewing domain learning in this way, learning to make sense of complex data through classroom inquiry means developing a disposition to reflect on inquiry artifacts, connecting them with a coherent data context.

How do students develop more reflective inquiry dispositions?

Reflection is a ubiquitous sense-making process, which can both contribute to and detract from the development of domain understandings. It involves problematizing elements of an experienced situation, and making conceptual connections between these problematic things and other elements of current or prior experience. Reflection can be more or less explicit, and more or less relevant for inquiry. We have seen students problematize some elements of inquiry situations (curriculum artifacts, tasks, words, etc), while treating others as non-problematic or routine. Similarly, we have seen students develop accurate domain understandings about things they have problematized, but we have also seen them make domain-irrelevant and incorrect connections to these same problematic artifacts.

Our analysis suggests that reflection is central to accurately making sense of complex data in a given domain of inquiry. However, it also suggests that reflection is central to *inaccurate* characterizations of inquiry artifacts, and *domain-irrelevant* conceptions of classroom activity. Reflection is not necessarily our friend – its relationship to domain learning is problematic. Problematizing is not an end in itself – it is a potential step toward developing domain-relevant understandings that can guide further inquiry.

We have seen LaTanya problematizing data items in terms of her color preferences. These are examples of students making sense of inquiry tasks and artifacts from domain-irrelevant perspectives. Importantly, our framework has enabled us to show how this apparently meaningless kinds of reflection can be closely related to the same students' domain-relevant reflection patterns.

Claim 2: Reflective inquiry dispositions develop out of inquiry-irrelevant dispositions

More reflective inquiry dispositions – those that lead to more productive reflection in the domain – do not replace less reflective dispositions. Nor are they developed from scratch, built out of newly-learned strategies. Rather, they develop out of existing modes of participation, as students redirect domain-irrelevant habits of mind increasingly toward the data context.

This means that students' patterns of domain-irrelevant reflection provide important information about how they can develop domain-relevant reflective patterns. For example, LaTanya's tendency to connect inquiry artifacts to her personal interests was not replaced by her increasing habit of connecting them with domain concepts. Rather, she spent more time discussing these artifacts, and did so with respect both to the domain, and to her personal life.

While these observations may seem logical and obvious with respect to any one child, the larger claim has theoretical importance for research and instruction. We often distinguish between on-task and off-task behavior, or look for evidence of a student following – or not following – a particular reasoning strategy. Especially in inquiry activity, in which students are meant to take considerable responsibility for directing their own work, these kinds of characterizations should be colored by an understanding of a reasonable *dispositional* learning trajectory. Where might this student be heading, given her personality and the intended mode of reflective thinking? The distinction between on-task and off-task should involve not only understanding the curricular assignment, but also envisioning a reasonable trajectory from less-reflective toward more-reflective conceptions of each task.

Claim 3: Content learning and group interaction modes are interdependent

Changing dynamics of group interactions are important mediators of the process of individual dispositional change. Patterns of group activity over time can afford more domain-relevant reflection in certain ways, and at the same time can inhibit domain-relevant reflection in other ways. Even when students are not working in a small group (e.g. individual work at the computer, or whole-class discussion), their reflections are mediated by their mode of participation in an activity system.

For example, the development of "comfort zone" patterns of group interaction afforded LaTanya's increasing tendency to problematize curriculum artifacts (e.g. the clay model) and some tasks (e.g. identifying boundary zones) with respect to multiple Data Context elements (real-world referents, domain concepts, and data patterns). However, the same "comfort zone" mode constrained the extent to which she problematized other tasks (e.g. debating plate predictions) and her own domain understandings (p. 101).

The development of productive patterns of reflection in inquiry is a process that brings together the constructs of "individual cognition" and "social context." The analysis has shown how intellectual and social development are intricately interconnected in

observable ways. Strengths and gaps in domain learning for particular students can be understood in terms of the affordances and constraints of their group's interactive mode, and their own participatory roles, for reflection.

The conceptual understandings developed by individual students are manifestations of the patterns of problematizing and connection that developed in their group's interactional mode, and of their own patterns of participation. The patterns of reflection that are practiced in activity are appropriated by participants. Classroom activity systems mediate what patterns are practiced, and how.

This interdependence of content learning and interaction patterns suggests the unity of "learning through reflection" and "learning to reflect." In fact, the two processes are the same: the kinds of reflection one practices establish the kinds of understandings that remain after (Hiebert, Carpenter et al. 1996). Inquiry learning is a coherent process of change taking place both in the realm of conceptual understandings, and also in the realm of modes of participation in social activity. Pedagogical discussions too often separate learning inquiry processes from domain-knowledge outcomes. Rather than concern ourselves with *either* learning concepts and skills *or* learning inquiry dispositions, we can use the framework to represent the ways changing modes of participation in activity mediate different understandings of science concepts.

How do elements of classroom activity systems interact to mediate dispositional learning?

The most important question is how to characterize the learning processes of reflection in inquiry. Learning to reflect productively in a domain of inquiry is a process of accommodating one's modes of *problematizing* and *connecting* in inquiry activity to a particular family of concepts. This has been described as bridging the Task Context to the Data Context.

It is clear from the case studies that reflection in inquiry must be cumulative rather than simply repetitive: in order to build domain understanding, reflective connections must become routinized, enabling new kinds of problematizing. In LaTanya's case, we have seen how she built from problematizing materials only in terms of group fairness issues, to also problematizing data patterns in terms of complex models and domain concepts. We have seen how group interaction patterns enabled and constrained this student's opportunities to build data-context connections.

Claim 4: Reflection in inquiry is a shared, social process

Making sense of activity, for a given student, is part of a highly interactive process of negotiating a mode of participation in an activity system, within which artifacts and ideas take on meaning. We have seen that particular modes of participation afford and constrain particular kinds of reasoning about data, and learning to reason about data in new ways involves developing new modes of participation in activity systems.

Reflective inquiry activity – problematizing artifacts (material or conceptual), and connecting them with domain ways of knowing – can be shared within and between activity systems. Holding something problematic can be a social activity, either by group construction of the problem, or through an individual sharing a problem which is appropriated by others.

Since the construction of the meaning of any given task is a negotiated process, decisions about what to problematize are shared decisions. Even the choice of words students and teacher settle on for describing inquiry artifacts significantly shapes the kinds of reflection each individual is likely to experience. When an individual student is confused or curious about something, the flow of activity can either stifle or kindle this curiosity. We have seen students begin to pursue promising lines of reflection, and then abandon them in favor of another train of thought that takes root in the group.

This perspective is a shift from the way reflection is usually talked about in the literature. Reflection is commonly thought of as the quintessential individual activity. The social construction of reflective episodes does not negate the existence of individual reflection. We have seen in the data analysis examples of students having an individual "a-ha!" moment on several occasions. But the learning goal we set for them – to become adept at using a system of reasoning about data which is accepted in an existing community of scholarship – is at its core a social goal. It involves adopting the practices of a community (earth science inquirers), and in fact developing communal practices within the classroom.

Claim 5: Participation and interaction modes are sites of inquiry learning

A social representation of the processes of reflection provides us with conceptual tools for understanding, not just how students' thinking changes, but how we as educators can try to change students' thinking. This is the importance of identifying connections between the Task Context, the Role Context, and the Data Context – in particular through

the mediation of curriculum artifacts and teacher guidance. By locating learning within three contexts rather than one, the framework points us toward useful ways to frame instructional goals. Rather than thinking of "domain learning" and "social skills" as two different kinds of goals, we can use a sociocultural model of domain learning for framing socio-cognitive goals. The result may be a tighter connection between, for example, cooperative learning structures and curricular content standards.

Participatory modes in inquiry are more than routes by which declarative and procedural learning occur. They themselves are important sites of classroom learning. Becoming more reflective in inquiry, and hence developing more robust understandings in inquiry domains, includes developing a larger repertoire of roles one can play in group interactions. This is true especially in light of the fact that different participatory modes afford domain-relevant reflection in the context of different group patterns.

Summary

Our analysis of small-group inquiry suggests that learning for individual students – the development of new understandings and dispositions – is mediated by patterns of activity in the "task context." This activity in turn is mediated by the norms of the group working together, the artifacts students work with, and the teacher's guidance – all of which contribute to the students' conceptions of the tasks and strategies they are using. This configuration of factors interact with each student's own understandings and role, to shape the way she thinks about her plotting stickers: as colored dots, or as earthquakes of different magnitudes.

We have seen that reflection is a way students can invest the artifacts of inquiry with deeper meanings, and that individual reflection can be enhanced by being shared in the group. Our curriculum designs have attempted to take advantage of what we are learning about reflection, to provide artifacts that will afford multiple chances to reflect, from a variety of meaningful perspectives. We have tried to design artifacts that afford reflective discussions among students and teacher.

We have seen that different students – and different groups – will find different elements of the situation problematic, and that this depends as much on norms and roles as it does on design. Our designs have suggested a flow of activity in which data-rich artifacts are used by students in different ways at different time – e.g. to interpret and make a predictive model, then to use this model for a subsequent modeling activity, then as a prop for telling an inquiry story. This trajectory is intended to provide multiple

opportunities for different groups to problematize different aspects of these artifacts, and to suggest connections with different elements of the data context.

By conceiving of reflectiveness in inquiry as a disposition which develops through individual roles, in a space defined in great part by interactional modes, we lay the foundation for rethinking both instruction and curriculum design. The framework locates both instruction and design in a relationship with the data context and the role context. In the next section we revisit some of our design assumptions in light of this perspective.

Conclusions and future research

The framework developed in this study is meant to suggest an approach for studying learning. The heart of the approach is finding relevant representational schemes to connect cultural, conceptual, and activity-bound perspectives on change in an activity system. Future work in this vein may enable us to characterize factors mediating learning with a good deal of contextual validity – building our understanding of how culture, activity, and knowledge connect with one another in everyday activity.

Jean Lave's admonition not to impose categories like "expert/novice" on situations which are better understood using the constructs "jock/burnout" (Lave 1990) should not lead us to study the social and ignore the academic-conceptual. Rather, Lave's point is that we need to understand the social and academic contexts of activity in their relation to one another. I propose that we attend to conceptual understandings as part of the role/identity context, while at the same time attending to their relationship to instructional designers' intentions in the data/domain context. Patterns of social interaction are the arena in which these two contexts interact. These mutually-informing perspectives should not be separated.

The specific graphics and constructs developed here are not meant to be generically applicable to all other classroom inquiry studies. Future work to develop this kind of approach should propose other representations of culture, identity, and activity systems, which enable us to identify foci of reflection. Our goal should be to find multiple systems for representing participants, curricular constructs, and classroom activity, maintaining the integrity of each of these constructs, while attending to the most relevant connections among them.

Future directions: Foregrounding other perspectives

Reflection, as operationalized here, promises to be a productive lens through which to analyze activity. Reflection in small-group inquiry activity, without the teacher's immediate presence, seems to take on a different character than reflection in whole-class discussion, or reflection during individual work. These differences can be productively explored in an attempt to further develop the constructs of reflection, problematizing, and suggestion proposed in this study.

This study has not investigated the complexities of teachers' roles in classroom inquiry activity systems. Representing these roles as more than one element of the task context ("teacher guidance") will be a big step forward in developing this kind of framework. While a teacher is one participant in activity, and as such can be represented using the role context (as with students above), the unique mediational role of the teacher might be better represented as a fourth context, the instructional context. This approach would enable us to focus on the relationship between the teacher and each of the other three contexts, a valuable perspective for understanding teaching strategies and teacher learning.

Dispositional learning has been explored here within a particular activity context – the development of interactional modes (roles) which afford reflective connections between an activity system (task context) and a family of conceptual understandings (data context). The question of "transfer" – the viability of newly-developed reflective dispositions in other settings – may be reconceived in this framework as *role development across activity systems*. Understanding transfer in this way requires us to examine more closely the relationships among roles, understandings, and identities.

We can pursue this line of investigation by foregrounding what I have called the role context, and examining its relationship to multiple activity systems (task contexts) with respect to particular domain understandings (data context). This could include looking at non-inquiry activity, less-structured inquiry, whole-class discussion, and any number of other common patterns of classroom interaction.

Similarly, the value of particular curriculum artifacts for mediating access to domain understandings could be a foreground focus of such a study. For this purpose we would expand the "artifacts" element of the task context, examining its relationship to the Data Context. This perspective could tie learning outcomes more directly to design intentions, grounding this work in curriculum design principles.

Connecting the framework with concrete learning objectives

In the analysis presented above, individual students' conceptual understandings in the domain (before, during, and after the unit) were identified using traditional pre-post interview data and other evidence. However, precise states of understanding of particular concepts (e.g. how accurate is a student's characterization of the direction of plate motion at a buckling zone) are not represented in the three-context framework. Rather, the framework is used to represent changes in patterns of reflection.

But specific conceptual learning objectives (e.g. *student should be able to define and identify a buckling zone*) should not be seen as separate from the framework proposed here. A set of specific understandings central to the domain underlies the representation of the Data Context. If we were to annotate the elements and connections of the Data Context, we could represent such understandings in great detail, even in such a way that they could become test questions (see Figure 2.3 for an example). This would be the next level of detail at which the proposed framework can be used to study learning.

The framework can also be valuable in developing learning goals of a different kind – dispositional learning goals. By grounding dispositional development in terms of domain-relevant reflection, it moves this kind of development out of the category of "social skills" and brings it more centrally into focus as a primary target of instruction. Role in activity becomes a formally recognized site of learning in the framework developed here, providing us with language to frame learning goals for developing reflective inquiry dispositions. Future work in this vein can seek to understand particular trajectories of dispositional learning that could be valuable for a wide range of students, and the relationships among various types of group interactional modes, teaching strategies, curricular designs, and individual students' dispositional learning.

Conclusion: learning as a coherent change process in multiple contexts

The heart of this approach is conceiving of learning as change of individuals with respect to activity systems, identity, and conceptual relationships. I have attempted to represent the unity of these three contexts in one coherent view of change. The value of this view will be measured in our ability to use it to design effective instructional tools.

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