DISCIPLINE-SPECIFIC PATTERN OF REPRESENTATION

ACROSS TEN MIDDLE SCHOOL CLASROOMS

by

AMY ALEXANDRA WILSON

(Under the Direction of Donna E. Alvermann)

ABSTRACT

This study, framed in theories of social semiotics, describes discipline-specific patterns of representation used across three disciplines—earth science, English, and mathematics—as they were taught by seven middle school teachers in the Southeastern United States. Under the assumption that each discipline would be characterized by distinctive patterns of representation because it addressed specific kinds of content, this study sought to (a) document those patterns; (b) speculate on why those patterns were prevalent in each discipline; and (c) describe reading and writing practices surrounding those patterns. Toward this end, the author observed the teachers for a total of 402 lessons ranging from 50 to 90 minutes each. Over the course of eight to nine months for each teacher, the author typed field notes of her or his instruction, took photographs of classroom artifacts such as handouts and whiteboard drawings, and conducted between four to nine interviews per person regarding representations used in the classroom. To describe the patterns of representation used in each discipline, the author and a colleague coded the data by identifying the types of representation that were used. To theorize what these particular types of representation might have afforded teachers and students across acts of communication, the author selected three video segments from instructional episodes in each discipline, based on their inclusion of the most common modes as indicated by the frequency count, and analyzed them using a multimodal concordance chart. The findings suggest that earth science relied heavily on gestures and a variety of iconic images as a means for representing movement and change on Earth; English relied heavily on written words as a means for addressing characteristics of language and intangible concepts such as characters' motivation; and mathematics relied heavily on numeric symbolic combinations and abstract images, with gestures to point out connections between representations, as means for helping students visualize patterns and solve problems. The author describes specific reading and writing practices surrounding these modes and concludes with implications for disciplinary literacy instruction as the development of *metarepresentational competence*.

INDEX WORDS: Adolescent Literacy, Social Semiotics, Disciplinary Literacy, Science Education, English Education, Mathematics Education, Representation, Affordances

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INTRODUCTION

A group of four sixth graders sits together at a mineral center, reading the instructions that direct them to scratch samples of calcite and fluorite with a copper penny and a steel nail. They record their observations, noting which mineral is harder, then read Mohs Hardness Scale in their textbooks in order to compare the calcite and fluorite to other minerals. After rotating to the next center, the students test the property of *streak* by sliding hematite and pyrite across a white ceramic tile, recording their observations, and reading a brief section in their textbooks about streak. At the fifth mineral center, students place fluorite with a pre-determined mass in a graduated cylinder with 50 milliliters of water, record the new volume of water, and calculate the density of the sample by dividing its mass by its volume. At other mineral centers, students participate in similar activities to learn about other physical properties of minerals, such as cleavage, luster, and crystal structure, often using photographs in their textbooks as a reference to compare to the minerals before them. At the final center, each member of the group rubs a finger against pieces of halite, licks her or his finger, and then records how it tastes.

Another teacher introduces the concept of *style* in writing by displaying a photograph of a character from a popular television show and asking students to notice her distinctive clothes that were designed to “grab your attention.” She continued, “We all have different styles, don’t we? Like, for example, I love how Sarah [a student in the class] dresses. I think Sarah has style. But is my style the same as Sarah’s? No…I know I look like an old schoolteacher, but I would hope some days I would have style.” After showing paintings from Van Gogh and Picasso and noting differences in style, she plays three songs and summarizes students' analysis of them: "The first one was kind of low and mellow and friendly. The second one was real jazzy, right? Expressive. The third one was downright mad, right? He was angry. He was yelling in that microphone. So they had distinct voices, didn't they? Authors, when they write, they have distinct voices, too."

To illustrate these distinct voices, the teacher reads excerpts from *Pink and Say* (Polacco, 1994), a somber children's story set during the Civil War, and *The True Story of the Three Little Pigs* (Scieszka, 1989), a parody of the original tale with the same title. Based on the illustrations and the word choice, students identify that the second tale was "trying to be funnier and not as serious [as the first]." The lesson ends as students select characters, write voice-filled letters from their point of view, and share them with the class.

In another classroom, the whiteboard displays seven words: *ratio: compares two things; compares two parts.* Students have been discussing the meaning of these seven words since the beginning of the period, providing examples of things they could compare and writing ratios in different ways—as a fraction, with a colon, or with the word *to.* The teacher warns students that they would have to look at the context of a given problem to determine whether a number that looked like ½ was a fraction in which the line stood for *division*, or a ratio in which the line stood for *to* as a comparison. After counting how many boys to girls were in the class (eight to sixteen), students stand in the hall, boys lining one wall and girls lining the other.

"We can see our ratio, eight to sixteen," the teacher says. "Now if we wanted to use everybody and make even groups, is there a way we can do that?" A student responds, "Divide the boys into four groups or two groups of four," and the teacher rejoins, "Okay, if we divided the boys into two groups of four, how many girls would need to be in each group?" Students rearrange their bodies accordingly, with boys dividing themselves into two groups of four on the right side of the hall, and girls standing directly across from them in two groups of eight on the left side of the hall. The students name other groupings they could make—two to four, one to two, eight to sixteen—and they again rearrange their bodies accordingly. As a whole class, they record the different types of groupings in a table, noting patterns in the data such as “the denominators can be divided by two,” “every numerator is half of the denominator,” and “they’re all equivalent to one over two.”

As these examples illustrate, learning across the disciplines can require students to interact with a variety of representations as they examine minerals, listen to music, understand and use the lines on a measuring instrument, rearrange their bodies in space, organize numbers by placing them in tables, and participate in a wide array of related activities. Instead of being peripheral add-ons to learning, multiple forms of representation can be central to reaching disciplinary goals. This book is based upon the premise that multiple representations can be considered *texts* (Kress, 2003)—from the spatial configurations of bodies in the hall, to the different styles of clothing pointed out by the language arts teacher, to the photographs of minerals, and more. Students “read” and make sense of these and other types of representation, using them to construct their understandings of disciplinary content.

If discipline-specific ideas can be communicated through artwork, rocks, gestures, and other forms of representation, then a different set of questions can be asked of disciplinary literacy instruction: What might it look like if it rigorously accounted for multiple forms of representation? For example, how might teachers provide comprehension instruction if their primary texts are rocks or the spatial configuration of bodies in the hall? How might teachers reconceptualize writing across the curriculum as representing across the curriculum, teaching students how to design and combine forms of representation that would best enable them to meet discipline-specific purposes for communication?

Disciplinary Literacy Instruction as Instruction in Representation

A longstanding but relevant critique (e.g., Herber, 1978; Moje, 2008) exists against many recommendations for disciplinary literacy instruction: They present literacy in a generalized manner. For example, people may recommend that students use generic comprehension strategies such as *making connections, inferring, summarizing,* or *predicting* as they read texts, regardless of the content of the text (e.g., National Reading Panel, 2000). Likewise, people may recommend writing instruction based in generic processes such as *brainstorming, making concept maps,* and *revising,* regardless of the writing task (e.g., Elbow, 1981; Murray, 1987). The general ability to self-regulate one's reading and writing processes may indeed hold the potential to improve students' comprehension or writing across disciplines (Draper, 2002; Klein, 2006), but critics (Conley, 2008) have asserted that this type of generic strategy instruction is simply not enough to prepare students to meet the challenge of reading and writing domain-specific texts required in each discipline.

Instead, researchers (Moje, 2008) have called for literacy instruction that forefronts the concerns of each discipline, a call that has been met with research from different approaches. Alvermann and colleagues (Alvermann, Friese, Beckman, & Rezak, 2011), for example, used a critical framework to describe conflicting values of experts in reading education as compared to experts in mathematics education. Conley and colleagues (Conley, Kerner, & Reynolds, 2005) approached the issue from a sociocultural lens, arguing that many recommendations for disciplinary literacy instruction do not account for the needs, interests, and cultures of individual learners from particular communities. Shanahan and Shanahan (2008a; cf. Shanahan &

Shanahan, 2008b) approached the issue from a cognitive perspective by interviewing experts in each discipline about how they read texts and by noting discipline-specific regularities in their ways of thinking. They proposed that mathematicians are more concerned with whether an argument is logical, cohering with other accepted postulates that are assumed as given, whereas scientists may evaluate the methods by which an experiment was conducted and by which data were analyzed and reported. Literary critics, in contrast, may be more concerned with a text's overall aesthetic value, evaluating a text in regards to whether or not they like it.

As these examples suggest, the problem of how to provide effective content area literacy instruction—the kind that is authentic to the discipline, resonant with teachers, and meaningful for diverse learners—is complex and multi-faceted. This book offers another possible approach to this problem by framing disciplinary literacy instruction in terms of the kind of representations used by teachers of each discipline. The vignettes that opened this chapter attest to the fact that teachers and students can use a variety of sign systems—such as gestures, images, and music—to understand and communicate core disciplinary concepts. This book is based on the premise that effective content area literacy instruction should rigorously account for of these types of representation and their attendant reading and writing practices. After describing these patterns of representation, the book uses them as a springboard to imagine new possibilities for disciplinary reading and writing instruction that accounts for a variety of representations both within and across disciplines.

What Is a Text?

A few central terms and concepts will lay the foundation for a later discussion of how and why the nature of representation differs according to content area, with subsequent implications for how reading and writing instruction might also differ. The first of these terms is *mode*, which can be defined as a “socially shaped and culturally given resource for making meaning” (Kress, 2009, p. 54). Examples of modes include *images*, *gestures*, *music*, *three-dimensional models, clothes, spoken words,* and *written words,* each of which is a fully articulated system for making meaning with its own unique structures and forms that can vary depending on the social group that uses it. For example, *clothes* in Renaissance England were made according to different patterns and materials than *clothes* worn by modern-day baseball players, but in both contexts, *clothes* can indicate meaning about the identity of the wearer such as the social groups with which he or she affiliates. Likewise, *written words* may be structured according to different patterns—such as narratives in English and observations in science—that indicate meanings about the goals of people in each discipline.

As teachers and students seek to communicate and to solve problems within their disciplines, they combine modes that most fully enable them to reach disciplinary goals. For example, consider an earth science teacher who wants her students to learn about neap tides and spring tides, which are caused by the gravitational pull of the sun and the moon on the earth as the three celestial bodies align in particular configurations. Because the spatial nature of this relationship is important, a mode that enables the easy viewing of spatial relationships may be the most apt way to convey this physical phenomenon.

In this case, the teacher could assign roles to different students as the earth, the sun, and the moon—asking them to revolve their bodies around each other in certain positions while the distant “sun” and the closer “moon” both exerted their gravitational pulls on the “earth” by pretending to pull that student toward them. An image such as a diagram would also enable students to view the spatial relationships between the three bodies at different points in the lunar cycle. As compared to the students’ physical actions, an image would convey greater precision in regards to the size, shape, and relative distance between the sun, earth, and moon. Written words, however, would not enable the students to “see” changing spatial relationships—including the different spatial alignment for each type of tide—as quickly or as easily as the diagram and the students’ bodies moving through space.

The concept of *affordances* (Gibson, 1979; van Leeuwen, 2005) is based on the premise that different modes lend themselves to representing certain aspects of the world more easily and powerfully than other modes. Images, for example, are governed by the logic of space and consequently afford the visualization of spatial relationships (Kress, 2003). Under this theory, written and spoken language, which have long been focal points of research in literacy education and related fields (Norris, 2009), are seen as but two means of communication that are best understood as being only *part* of teachers’ and students’ communicative repertoire. Students also make sense of various types of images, demonstrations, objects, and more—each of which can be a legitimate and powerful means of expression.

The concept of affordances requires definitions of content area *texts* to be expanded beyond traditional connotations of *novels, textbooks,* and even *websites.* Instead, a *text* becomes any instance of communication in any mode or combinations of modes, including those modes that do not appear on a page or on a screen. When *text* is viewed in this way, content area teachers and students become text designers who marshal a variety of multimodal resources as they seek effective ways to communicate core disciplinary concepts. Students, too, become text designers who can use body movements, writing utensils, paper and poster board, computers, clay, combinations of clothes, and other materials to build and express their understandings of disciplinary ideas, eventually learning to fashion their representations in accordance with the conventions of each content area.

What Is a Discipline?

Defining what constitutes a given discipline is a notoriously contentious task for many philosophical and pragmatic reasons (Becher & Trowler, 2001). Disciplines constantly evolve as more knowledge is generated and made available through new technologies; as a result, what was once considered a sub-discipline of a given field—such as microbiology—is now considered a distinct discipline in its own right. To some, labels such as *mathematics* or *science* are unhelpful generalizations; instead, *geometry, algebra, chemistry,* or *physics* are more accurate, with terms such as *astrophysics* and *linear algebra* offering even greater precision.

Moreover, new technologies have led to increased international communication among peoples who have different cultural experiences with disciplinary concepts and practices (Appadurai, 1996; Rogoff, 2003), causing some to question Eurocentric conceptions of *mathematics, science,* and *language arts* that may not align with local ways of understanding the world and communicating one's experiences with it. These new technologies also enable new forms of representation in digital environments, leading some advanced practitioners in their respective fields to experiment with new, hybrid ways of constructing and representing disciplinary knowledge (Viégas & Wattenburg, 2011). Given these complexities, this book does not presume to delineate and define disciplinary texts as they are made within disciplinary boundaries. Any descriptions of disciplines should be taken as provisional heuristics intended as a springboard for discussions about possible trends in disciplines, rather than as statements about what disciplines are or should be.

At the same time, despite these complexities that make defining a discipline difficult to do, the three vignettes that introduced the book were probably easy to identify as science, language arts, and mathematics respectively, even though they were not named. What, then, causes different disciplines to be distinguishable from one another? Theories of social semiotics (Halliday, 1978; Hodge & Kress, 1988) begin to provide possible answers to this question. According to these theories, social groups can be recognized by the patterns of signs they create and exchange. Groups of mathematicians, scientists, literary authors, and others communicate particular ideas using particular genres and forms of representation as they work to achieve related a set of goals within each discipline. These people's texts both shape different disciplines and are shaped by these disciplines.

Imagine, for example, a mathematics teacher who writes $y = 6x$ on the board beside a two-column table as she asks a student to read the instructions in the textbook: "Use the following rule to find the numbers in this table." Pointing back and forth between *x* and the *y* in the equation, the teacher explains, "This is my x value; this is my y value. Every time I put in x into this rule, I'm going to get out a y. So I put in a one and I get out a y equaling six. My output would be a six." Soliciting answers from the students, she fills in a set of remaining values for the two-column table, which she graphs on the board under the students' direction. After further practice, students likewise use simple equations to complete two-column tables and draw line graphs.

In this case, the discipline of mathematics was produced through multiple texts: the teacher's and students' verbal interactions, graphs, tables, numbers, and the teacher's pointing that served as a mediator between these texts as she showed how *this* x in the equation corresponded to *this* number in the table that corresponded to *this* many boxes to the right of zero on the coordinate plane that was used to construct the line graph. Through these texts, the teacher—who orchestrated the combinations of representations—communicated both explicit messages about how to use rules to construct tables and "implicit messages" about the nature of the discipline (McDiarmid, Ball, & Anderson, 1989), including the methods by which mathematicians solve particular sets of problems and the forms of representation they use as they structure and substantiate claims.

Here one might protest that professional mathematicians would likely not spend their time changing simple equations into tables, nor would they line up in a hall to communicate the concept of ratio. Likewise, professional scientists would not pull on each other's arms while standing in particular spatial configurations to discuss the latest research on tides during an annual meeting of the American Association for the Advancement of Science. Bernstein (2000) offered possible explanations for this discrepancy by asserting that the goals of disciplines change after they are recontextualized and taught within academic settings. According to Bernstein, the "primary context" or private sector is concerned with producing a given discipline, whereas the "secondary context" or K-12 school system is concerned with its reproduction and transmission in tightly-regulated ways.

In practical terms, this recontextualization has several implications for how disciplines in K-12 schools may be substantially different than disciplines as they are practiced by advanced professionals. First, rather than being approached as a set of pressing issues that remain to be solved and understood, disciplines can be presented as a known body of facts and concepts that students are expected to acquire. Second, in a society where political institutions are interested in regulating and measuring disciplinary knowledge in efficient ways—for example, through end-of-year multiple choice tests—students may read texts that professionals do not typically read (such as questions on worksheets) and respond to these texts in ways that are not typically required of professionals (such as short answer responses). In this sense, when students answer multiple choice questions across several classes, they may be participating in a form of *school* discourse rather than an authentic *disciplinary* discourse.

Other consequences result when disciplines are recontextualized from communities of practicing professionals to groups of students in schools. In the words of Bezemer and Kress (2008), this recontextualization “involves the re-presentation of the meaning materials in a manner apt for the new context in the light of available modal resources” (p. 184). Part of this “new context” includes a consideration of the needs, interests, and background knowledge of those who are communicating with each other. Whereas seasoned mathematicians may be able to communicate almost exclusively using strings of numbers and symbols, students who are first learning the meanings of these symbols require additional supports. Thus, although mathematicians may not ask people to line up on different sides of the room during presentations at the American Mathematical Society, this activity may be nonetheless be an appropriate way to communicate the concept of ratio to twelve-year-olds as did the teacher who introduced this chapter.

Part of this “new context” also includes, as Bezemer and Kress (2008) pointed out, a new set of “available modal resources.” To illustrate this concept, they described how construction work is recontexualized as “woods” classes in schools where students usually do not have access to the materials and tools that professional builders have. As an another example, scientists often have a variety of resources at their disposal, including expensive and sensitive technologies that enable nuances of measurement or that enable people to see distant or microscopic phenomena. They can go out in the field, collecting samples and examining matter from different regions. They can conduct experiments on organisms and theorize and communicate their findings using advanced technologies. Because schools have given sets of economic resources and safety regulations, the semiotic resources available to students may be different from those available to advanced practitioners. These differences in semiotic resources can result in differences between professionals and students in terms of how they are able to generate and express knowledge as they seek to gain and demonstrate proficiency.

Despite these differences in primary and secondary contexts, when disciplines are recontextualized in K-12 schools, their "meaning materials" can still remain recognizable as being part of the field of *geometry, oceanography,* and so forth, retaining many features of the representations used by advanced professionals (Roth, Pozzer-Ardenghi & Han, 2005). Students can write using the same techniques as novelists, for instance, such as dialogue or imagery, and they can use measuring instruments as they observe and record aspects of natural phenomena, as practicing scientists do. Furthermore, school disciplines need not be conceived as the transmission of established knowledge that has been generated by advanced practitioners.

As Waldrip, Prain, and Carolan (2010) have asserted, "whilst established conventions and interpretations are no longer negotiated, it is also important for students to recognize that they once were, and this is still the case for some new procedures and findings" (p. 77). Students can participate in the same types of activities as practitioners did when they first established disciplinary conventions, such as trying to find the value of *pi* or generating the algorithm used for dividing fractions after discussing situations in which dividing fractions would be useful. Moreover, the judicious use of multiple choice questions and comparable texts can move toward making school-based disciplinary activities more aligned with the work of professionals.

Given these considerations, the question that framed this section—*What is a discipline*—may be changed to *What is a discipline as it is enacted in secondary schools?* A discipline in school is instantiated through a set of related texts—from diagrams to mathematical equations to verbal explanations to novels to photographs—whose patterns and uses are distinct from other disciplines. Although these texts are related in form and purpose to those generated by professionals, they are also different due in part to the needs of novice learners and the context of schools. Teachers draw from available semiotic resources (such as the materials in their storage closet or the movement of their bodies) as they enact disciplines on a daily basis, combining video clips, three-dimensional models, lab kits, worksheets, textbooks, interactive diagrams, demonstrations, gestures, objects, and other resources to communicate both the conventional knowledge of each discipline and the means by which that knowledge is constructed, substantiated, and evaluated. Each text—from *written instructions* on how to calculate the density of a mineral sample to a *spoken question* about the patterns in a ratio table—instantiates what it means to *do science*, *do mathematics*, and so forth. Teachers assume the role of text designers and directors as they plan the most effective ways to represent core concepts within their respective disciplines and as they ask students to construct texts that will likewise promote their understandings of these core concepts.

Reading and Re-presenting Across Disciplines

When reading and writing instruction across the curriculum is reconceptualized to rigorously account for these modes, it can draw students into conversations regarding how and why people might choose to represent disciplinary concepts using in particular ways. These discussions, rather than being “add-ons” to disciplinary learning, are central to it, with the potential to enhance students’ engagement with core concepts and problems in each discipline. As Hubber, Tytler, and Haslam (2010) argued, “The demand to explore, generate, and refine representations constitutes a demand to think deeply about the [discipline] itself, and the coordination of representations in constituting explanations and claims is central to the learning process" (p. 25).

Although Hubber and colleagues were talking about research they had conducted in science classrooms, the exploration and generation of multimodal texts in other subject areas are equally important because these texts are the mediums through which students construct and express their understandings of each discipline. In mathematics, for example, a question such as, *How might I represent the concept of ratio?* opens up conversations about what ratio *is* and *is not* and how some representations might be problematic in how they demonstrate this concept.

Indeed, the development of new forms of communication is what made certain types of mathematical operations possible (O'Halloran, 2009), and bringing students into conversations about how to communicate mathematical concepts can help them to engage in the kind of thinking that mathematicians have been addressing for centuries. English, the subject that has historically been designed in part to address how people can craft different types of texts—with explicit instruction regarding the structure and characteristics of the final product—is likewise a discipline where discussions of representation meet disciplinary goals of communicating in expressive and persuasive ways (National Council of Teachers of English/International Reading Association, 1996).

This emphasis on representation across the curriculum does not assume that all multimodal learning is the same. Instead, different disciplines are characterized by specific patterns of modes that are combined and used in discipline-specific ways, and the mere presence of a mode does not mean that it is essential to helping students understand disciplinary content. In some lessons, for example, an image may be present but ancillary to the teacher's goals—in fact, a student may not even look at it except in passing (e.g., a cover for a literature anthology)—whereas in other lessons, an image may be the focal text that students read as they build understandings of a particular concept (e.g., the relative distance and size of the inner planets as compared to the outer planets in the solar system). Thus, disciplinary learning is multimodal in particular ways, with particular modes frequently carrying more significance and utility in certain disciplines.

This book offers a description of the discipline-specific patterns of texts that students read as they leave elementary settings and enter secondary schools, often being taught for the first time by teachers who have expressly specialized in given content areas. Specifically, this book describes the characteristics of texts used in earth science, English, and mathematics classrooms recognized for excellence. One chapter is devoted to each discipline, including:

- a broad description of its goals and learning objectives as a precursor for understanding why practitioners in each discipline might engage in particular kinds of semiotic activity
- a description of the teachers' conceptions of the discipline, including their daily objectives
- a record of the types of representations that teachers used to help students reach those objectives, with the modes listed in order of frequency of use
- a description of how multimodal texts in each discipline were distinctive in both their *characteristics* and their *uses*
- a discussion of reading and writing practices that were specific to each discipline
- implications and recommendations for explicit disciplinary reading instruction, writing instruction, and critical literacy instruction.

Developing communicative proficiency in even one discipline is a demanding task. It requires students to (begin to) structure written language in accordance with disciplinary conventions (Moje, 2008), an undertaking that becomes even more complex when one considers how advanced practitioners use written language in conjunction with different modes to form and express new understandings. Potential difficulties in learning how to structure multimodal texts are again compounded when middle and high school students engage with several disciplines on a daily basis, held to expectations that they should communicate in forms that meet criteria specific to each discipline. Consequently, to address the fact that students are charged with learning representational practices across multiple disciplines, the concluding chapter addresses how students can be supported in developing overarching frameworks for thinking about representations *across* disciplines as they consider how the uses and forms of texts in each discipline are different, why they are different, and how these differences have implications for their own writing.

Background

The lessons and photographs used throughout the book were collected as part of a study of seven middle school teachers in the Southeastern United States, each of whom had been recognized for excellence in teaching by several sources: their administrators, their colleagues, and/or university professors who had placed student teachers in their classrooms or who had worked with them through different professional development venues. Several teachers had been nominated for or had received Teacher of the Year multiple times, earning accolades from a national teaching organization and from their respective districts for high end-of-year test scores, leadership, and innovative teaching. Throughout the duration of the study, six of the seven teachers each taught two different content areas, both of which they were highly qualified to teach according to state and federal standards. It was hoped that data from these teachers would provide insights into how effective teachers represented their respective disciplines and how they supported their students in constructing representations as well. (Read Appendix A for more information on the teachers and for information on data collection and analysis.)

Despite the teachers' numerous accolades, however, this book does not purport to outline how disciplines should be taught by other teachers. Furthermore, although the participating teachers were selected based on their reputations for excellence, this book does not make claims in regards to whether individual lessons were "good" or "bad" and to what extent. The purpose of the book is not to *evaluate* the quality of teaching according to disciplinary or institutional standards, but instead to *describe* the teaching practices of those who demonstrated the potential to help their students engage in disciplinary learning in powerful ways. It is intended to open up conversations about the discipline-specific nature of texts in each content area, including discussions regarding how teachers might provide explicit instruction on multiple representations that have previously not been systematically addressed as legitimate and relevant *texts* and sources of learning.

CHAPTER 2

READING AND REPRESENTING IN EARTH SCIENCE

Earth science addresses the interactions that occur within and across Earth's major systems—its atmosphere, biosphere, geosphere, and hydrosphere—as well as addressing the earth's attributes in relation to other planets and bodies in the universe (National Science Foundation, 2010). Advanced practitioners in this field work in many specific sub-branches of science, including oceanography, mineralogy, climatology, volcanology, pedology, and more. As students learn basic principles that undergird these different branches of science, they develop understandings of the causes of many naturally-occurring phenomena that shape the surface of the earth and that shape humans' experiences with the natural world: tornadoes, hurricanes, earthquakes, volcanoes, mountains, weathering, erosion, global and local winds, tides, waves, currents, seasons, lunar phases, and more. At times, understanding the causes and nature of these phenomena can help people to predict and respond to them in ways that protect and enrich life.

As students in this discipline learn about how the physical world affects their lives, they also learn about how their actions affect the physical world. Discussions of global warming, renewable versus nonrenewable resources, human acceleration of erosion, the conservation of Earth's limited supply of freshwater, and other related issues are central to helping students make informed personal decisions that protect their local and global ecosystems. Students of earth science may also use their knowledge of the earth's systems and processes to effect change in their neighborhoods and communities. Examples of effecting change include advocacy for more equal distribution of resources and advocacy for more judicious uses of these resources as people maintain their homes, travel to work and school, and manage waste.

An awareness of temporal and spatial scales is important to many concepts in earth science. Humans have existed for about .004 percent of Earth's 4.6 billion-year history, which has witnessed the accumulation of dust and gas that separated to form layers of the earth, the formation of rocks over millions of years, and the evolution of life, to name but a few major events. Earth is about 149,597,870 kilometers from the sun—"far" relative to the distance that a vacationer might travel, but only one astronomical unit when measuring distances between bodies within the Milky Way. Moreover, one astronomical unit is but 1/63240 of one light year, another unit used to measure distances in space. As these examples and others suggest, scales in earth science often extend beyond everyday human perceptions of *far*, *a long time*, *hot*, *small*, and so forth.

As in other sciences (Halliday & Martin, 1993), earth science is concerned in part with classification into types. Students learn how practitioners have classified different types of rocks, minerals, soils, planets, layers of the earth, clouds, and more. These phenomena are often separated into types by their formation, composition, and other physical properties. To understand how phenomena are formed and how they develop certain physical properties, students must contextualize them within larger interrelated processes that drive continuous changes in the geosphere, hydrosphere, atmosphere, and biosphere. These processes include the water cycle, the rock cycle, convection currents in the mantle and atmosphere, gravity and inertia, and more.

These continuous changes that shape the earth frequently involve movement. From shifting tectonic plates, to rotations and revolutions in space, to the continuous flux of ocean currents, to the carrying away of weathered materials—Earth never stays still. Consequently, earth science depends heavily on spatial reasoning (Orion & Ault, 2007) as students draw inferences about physical phenomena based on their spatial position and/or the direction of their movement relative to each other. For example, the law of superposition has served as a foundational principle in branches of geology, which holds that sedimentary layers are deposited in a time sequence, with the oldest on the bottom and the youngest on the top. This law has implications for dating fossils as people make inferences about their relative ages based on whether they are above or beneath one another.

Similarly, students can make inferences about the age of crust on the ocean floor based on its spatial position relative to the mid-ocean ridge, through which magma is pushed out of the earth's mantle. Students can reason that rocks that are closer to the ridge are younger whereas rocks that are farther away are older. Indeed, questions about spatial relationships have driven major theories in earth science, such as when Alfred Wegener became curious about the somewhat puzzle-like shape of the continents and used this observation to fuel further investigations that led to his articulation of the concept of continental drift. As these and many other examples suggest, branches of earth science require students to understand spatial relationships among physical objects and to use their observations of these relationships to draw reasonable inferences.

As in other sciences, knowledge in earth science is constructed and claims are substantiated through repeatable observations and testable ideas which are made available for critique. As part of the process of scientific inquiry, scientists often read the natural universe with the aid of measuring instruments (e.g., barometers, thermometers, seismometers) that allow them to make precise comparisons across phenomena. Scientists also often read aspects of the natural universe with the aid of other technologies (e.g., microscopes, telescopes, satellites, digital cameras) that enable phenomena to be observed, recorded, and analyzed in increasingly sophisticated and nuanced ways.

Practitioners in different branches of earth science "read" more than the earth and the universe: They also read the work of their colleagues. They often read with a concern for whether a particular article or book is scientifically credible based on the methods by which the author collected, analyzed, and reported data that aligned with a testable hypothesis and based on how the author's inferences correlated with other accepted scientific theories and suppositions. A scientist's affiliation with particular social groups can influence whether or not her work is deemed as credible (e.g., a scientist may be hired by a particular construction company to conduct research on the environmental impact of the company's building projects), but if her report leads to repeatable results it can still be regarded as meeting the standards of a "quality" scientific text regardless of her personal affiliations.

Teachers' Conceptions of Earth Science

In a broad sense, scientific disciplines are based in the idea that people, curious about happenings in the world around them, continue to develop and refine systematic methods of inquiry to address their questions. Consonant with this view of science as a discipline of investigation, the teachers described in this chapter defined *earth science* as a way of teaching students how to develop questions and seek answers in relation to the natural world around them. In the words of Tracy, "Science is not just about learning a bunch of content but learning how to study your surroundings and study the world around you from a different point of view, like actually analyzing it instead of taking things for granted…being able to look at it and figure out how it works, why it works that way, what happens if you change one variable."

Many of the teachers' essential questions addressed ways by which students might "study the world around them," including questions addressing how to use models to reason about the earth, how to measure, how to keep clear and accurate records, and how to make valid tests (See Figure 2.1). In other lessons, these skills were at times embedded within a particular body of content. For instance, in a lesson whose essential question was *What are the layers of the earth?,* Grace's students practiced using indirect evidence to make inferences prior to learning about how scientists use indirect evidence such as seismic waves to learn about the nature of the earth's interior. As indicated by these essential questions, most of the teachers' instruction was dedicated to describing or classifying physical phenomena or inquiring into the causes of these phenomena as students studied change on Earth.

In Tracy's mind, reading others' explanations would not sufficiently engage students in these discipline-specific questions. Instead, she believed students should have opportunities to conduct explorations themselves. In the words of the American Association for the Advancement of Science (2009), "Scientists know that finding answers to questions about nature means using one's hands and senses as well as one's head" (Benchmark 12.C, para. 1). Accordingly, the natural world itself can be (at least theoretically) a central text—if not a foremost text—as students observe and manipulate it in earth science classrooms. In accordance with this view, Nancy Rae and Grace described their favorite science teachers as those who provided them with "hands-on" activities—from Nancy Rae's geology professor who required her to "go visit the Smoky Mountains and Gatlinburg and learn about faults and folds" to Grace's high school physics teacher who asked her to participate in activities such as "banging cars or playing pool" to illustrate Newton's laws.

When asked to “describe a teacher you liked who taught science,” Tracy likewise avouched, “I had a lot of really cool science teachers…and one thing that they all had in common was that they did a lot of hands-on. They did a lot of labs. We didn’t do bookwork….I think that when you just do bookwork, looking at the pictures, and filling in guided reading and section summaries and things like that, I think you miss a whole lot and science doesn’t become real.” Grace, too, described a bad science teacher as one who “just read out of the book and that’s all we did.”

Texts in Earth Science

If an exclusive reliance on bookwork is a hallmark of a less-than-engaging science teacher, then Tracy, Grace, and Nancy Rae were anything but. Collectively, textbook readings comprised fewer than 7% of total texts (see Table 1). Instead, they regularly integrated a variety of modes, including gestures and embodied representations, images, labs and demonstrations, and models and objects. Teachers used more representations per instructional episode in this discipline than in any other studied discipline to communicate phenomena on a changing earth as well as to communicate the processes by which people can draw conclusions about those phenomena.

Gestures and Embodied Representation

Gestures were the single most frequently used mode in earth science, comprising 14% of recorded representations and used in 102 of 175 instructional episodes. What is a gesture? In one sense, teachers’ hands may be constantly moving as they speak. However, much of this movement is what McNeill (1992) has called *beats,* or general up-and-down “movements that do not produce a discernable meaning” (p. 80). For the purpose of this study, *beats* were not classified as gestures that served a representational function because teachers did not purposefully use them to contribute to their instructional objectives.

Grace, Tracy, and Nancy Rae frequently employed other types of gestures, however, in more deliberate and focused ways. For example, Tracy placed her left hand in a fist to the left of her body, then put her hands (palms facing each other) apart in front of her body, then put her right hand in a fist to the right of her body, to indicate how the inner planets (represented by her left hand) were separated from the outer planets (represented by her right hand) by an asteroid belt (represented by the bracketed space directly in front of her body). Cupping her left hand, palm upward, while moving her right hand down from the cupped hand and wiggling her right-hand fingers, Nancy Rae demonstrated how leachate (the harmful liquid substance represented by her right hand) might leak from solid materials (her cupped left hand) in landfills, much "like a coffee maker, and you put the coffee grinds at the top, and you put the hot water through it. Coffee comes out of the bottom. Garbage is the same way. Garbage gets wet, what comes out of the bottom is a nasty juice called leachate."

As these examples and many others demonstrate, gestures in earth science were often not simply up-and-down movements that kept pace with the cadence of speech; instead, they were used for the purpose of helping students accomplish a particular task or understand a particular concept. Accordingly, gestures throughout this book are defined as "arm/hand movement or gross whole body movement designed to enhance students' understanding of the content, whose intended meaning is usually cued by or complemented by spoken words." Drawing from Kendon's (2004a) assertion that any classification system for gestures should be considered "useful working instruments for a given investigation, but they should not be thought of as more than this" (p. 85), this book uses and modifies concepts from established gestural classification schemes (McNeill, 1992; Wundt, 1973) to categorize the types of gestures used by the teachers described therein (See Appendix C for definitions of different types of gestures and Figure 2.2 for the types of gestures used in earth science). Gestures in earth science were used in two ways: (a) to "laminate" other forms of representation, such as images and models (Roth & Lawless, 2002); and (b) to extend, illustrate, and organize verbal speech.

Gesture as lamination. Roth and Lawless (2002) have used the term "lamination" to describe instances wherein science teachers used gestures over images. In over half of the instructional episodes in earth science that included gestures, gestures were used to laminate other representations. Two examples will illustrate how *movement*, *shape,* and *pointing* gestures laminated two-dimensional or three-dimensional texts.

The first example of lamination occurred when students were at the end of a series of lessons on sea breezes and land breezes. Grace displayed a diagram on a Smartboard in which a beach was on students' left, and the ocean was on their right (see Figure 2.3). Arrows on the diagram indicated the direction of a land breeze. Grace held up a globe in front of the diagram and said, "If you look at the globe, here's our land, right here, the land on the left [points to the coastal line of Eastern America], land on the left [points to the land on the diagram]. Water's on the right [points to water on the globe]; water's on the right [points to water on diagram].

"So if you were in California [points to California on the globe], you would have a picture with the land on the right [waves hand over right of the diagram on the board], and water on the left [waves hand over left of the diagram], but at night time the water would still be warm, and the land would still be cool. So your arrows would go, instead of this way [moves her hands in a clockwise motion over the diagram], this way [moves her hand in a counter-clockwise motion over the diagram]." A student then asked Grace what would happen if the land and water were not beside each other according to an East to West or West to East orientation, but instead at a North to South orientation, such as at the top of Australia. Grace used a repeated circular gesture over the top of Australia to show how sea and land breezes would also occur in locations where land and water were South or North of each other.

Tracy provided a second example of lamination in a lesson about weathering and erosion. She had asked her students to choose a photograph of various landscapes (e.g., rivers, mountains) that she had provided for them, to draw and explain a picture of what it might have looked like before centuries of weathering and erosion had occurred, and to draw and explain a picture of what it might look like after further centuries of weathering and erosion will occur in the future. To provide an example of how her students might complete this assignment, she displayed a photograph of a rock formation on the whiteboard (see Figure 2.4).

Tracy drew green lines over the rock to show how its shape might have appeared centuries ago, and she placed her hands together at a particular angle to indicate the shape of the rock before it had been weathered and eroded. She asked her students what might have happened to give the rock its current shape. When students identified that water had been hitting against it and carrying away pieces of rock in a form of mechanical weathering, Tracy elaborated, “Physically the rocks are being affected because you’ve got the waves hitting up against the side and taking things away, but chemically the salt goes in there [points to a part of the rock]…and makes it easier for chunks to break apart.” Tracy moved her hand down the green drawing to indicate how chunks could have been weathered and eroded away from the early rock (the green drawing) to form the present rock (the photograph).

As these examples demonstrate, gestures as lamination complemented models (the globe) and images (the photograph and diagram), providing affordances that each type of representation did not possess alone. In the first instance, gestures overlay the arrows on the diagram to show the direction of breeze, enabling students to see the invisible entity (the breeze) in a moving form rather than as a static arrow. Later, Grace's speech and gestures also established an imagined space over the diagram of the beach, in which left was right and right was left, and in which consequently the direction of the land breeze could change at the turn of her hand. In this sense, gestures were an essential feature in preventing students from developing the misconception that land breezes always move clockwise.

Similar to the globe and gestures that overlaid Grace's diagram, the green lines and gestures overlaid Tracy's photograph. The lines, coupled with the gesture indicating the rock's original shape, provided a visual likeness of the rock formation of long ago. By showing how chunks of rocks might have eroded into the ocean through her gestures, Tracy enabled her students to "see" the effects of weathering and erosion, processes that can take millions of years, in a matter of a few seconds. In effect, the gestures and speech transformed a still photograph, taken at one point in time, to a moving representation that indicated millennia of change. The use of pointing also focused students' attention toward particular visual features that were salient to the class's discussion of weathering and erosion. As in Grace's example, Tracy's gestures also worked with her speech to connect two representations: Through her gestures, the green lines (the laminated drawing) broke apart and formed the photograph. In earth science, *pointing*, coupled with other forms of gestures such as *movement* gestures, often served as a type of "glue" that enabled teachers' laminations to work together as a coherent package of meaning (cf. Roth & Welzel, 2001).

Gesture with speech. Gestures did not only serve to laminate other forms of representation. At times, gestures worked in conjunction with only verbal speech to form a coherent message. Common examples of *movement* gestures, used by each of the three teachers and their students, included moving two hands in various configurations to represent the three types of tectonic plate boundaries. For convergent boundaries, two hands with flat palms “collided” together, at times “crumpling” to represent the formation of mountains. At other times, one hand moved under the other to illustrate subduction zones that occur at some convergent boundaries. Divergent boundaries—with hands, each representing a tectonic plate, pushing away from each other—and transform boundaries (with hands, or plates, sliding past each other as in Figure 2.5) were also represented through gestures in each of the three classrooms.

Other common *movement gestures* used across classrooms included the use of one hand rising and sinking in a circular motion as teachers described the causes of convection currents. Teachers’ and students’ hands also represented the rotation or revolution of the earth, sun, and moon—for example, when Tracy’s left hand was a fist that represented the sun, and her right hand represented the earth that revolved in a circle around her left hand. While describing the effects of ice wedging, Grace’s hands represented a crack in a rock (see Figure 2.6) that had been filled with water that froze and became ice. “And then the water goes down deeper,” Grace narrated as she moved her hands farther apart, “The ice expands, and that causes the crack to get bigger” [moves her hands farther apart].

When used in conjunction with verbal speech, gestures can therefore serve to call students’ attention to a very particular or limited aspect of that phenomenon. In earth science, a discipline that relies heavily on spatial reasoning (Orion & Ault, 2007) and that addresses a constantly moving and changing earth, gestures were an apt means to draw students’ attention to salient concepts at the heart of the discipline. Arms and bodies, a readily available semiotic resource for teachers and students, enabled them to represent movements that might be invisible (e.g., convection currents in the air), that might be too large (e.g., planetary motion), or that might take too long (e.g., erosion) for them to see with the naked eye. For these reasons, it is perhaps not surprising that gestures were used in earth science more than in any other discipline and more than any other type of representation

Embodied representation. Embodied representations, similar to gestures in the sense that the body itself is used to convey meaning, were a similar type of representation occurring in 12% of instructional episodes. In a lesson on gravity and inertia, for example, Grace's student represented the earth who walked forward in a straight line due to *inertia,* until Grace, the sun, used her gravitational force to pull him toward her. Still wanting to move forward due to inertia yet still being influenced by Grace's tug, the student eventually settled into an orbit by walking around Grace. Similarly, in Nancy Rae's class, students' bodies represented molecules that were packed densely together in a solid, whereas they moved about more freely in the room as air molecules.

Tracy's students participated in a comparable activity when their bodies represented different layers of the earth as they stood at different distances from each other (the inner core was the most densely packed), while in a later lesson their bodies each represented individual planets as they stood outside at scaled distances from each other. In this latter lesson, Tracy described her students as being

> shocked when they saw how far apart the outer planets were from the inner planets, and how far apart the outer planets were from each other. Because they're used to seeing these models in the back of the classroom that are just in a line, they're nice and evenly spaced. Everything's hunky dory. They just don't get how big it is. And so, actually

> having that visual, they're like, "Wow, that's huge!" I mean they all, when we got to Jupiter, and the distance between Mars and Jupiter, they just started laying down their meter sticks, and they just kept laying them down and laying them down and they were like, "Oh my gosh, look at where we are, look how far away."

Even though the invention of *scale* enables people to communicate large distances on an 8 inch by 11 inch page or on a comparable sized computer screen, scales in earth science could be so vast that bodies in actual space, versus virtual space or page space, enabled students to visualize this scope more clearly. Like gestures, embodied representations were shaped out of an immediate semiotic resource that students and teachers always carried with them: their bodies. And, like gestures, they afforded the visualization of space and movement as students "read" the spatial relationships between their bodies and other bodies—either moving or still—at different distances. The sheer number of gestures and embodied representations that appeared in the earth science classrooms, coupled with the way that they were used to depict core concepts, suggests that these modes are not mere add-ons or superfluous decorations in earth science classrooms. Instead, they were central texts through which the discipline was constructed.

Images

Images, too, have historically been central to the construction of earth science as a means through which people have reasoned about problems and communicated their results (Giere, 1996; Rudwick, 1976). From Nicolas Copernicus, who drew the planets orbiting the sun in his heliocentric theory of the universe, to Alfred Wegener, who used maps of the world to support his hypothesis that all continents were once joined together, to Renee Descartes, who drew sketches of the earth's layers to postulate theories about how mountains are formed—images have long helped scientists articulate theories about the world and its relationship to other bodies in space (Robin, 1992).

Massironi (2002) suggested that scientific images comprise their own discrete class of representation, distinct from images in other disciplines, due to the unique function they serve. Specifically, scientific images are often used to *generate* theories or to *explain* aspects of a phenomenon, rather than to simply *depict* this phenomenon. For this reason, Baigrie (1996) has asserted that, at least in the field of science, "photos are the least informative" (p. xix) type of image because they contain so much of what Myers (1990) has termed "gratuitous detail and particularity" (p. 238). Drawings and diagrams, in contrast, can focus exclusively on aspects of the phenomenon that are salient to the argument at hand, depicting invisible processes through arrows and other symbols that allow people to build and express explanations (e.g., Hubber, Tytler, & Haslam, 2010).

The images that Tracy, Grace, and Nancy Rae used in their classrooms will be described in accordance with this continuum that ranges from *realistic* to *abstract* (Pauwels, 2006; Topper, 1996). Oftentimes, this continuum correlates with the purpose for which the image is used: Realistic drawings may be used as a means of observation and description, for instance, whereas more abstracted representations may be used as means of theory building, interpretation, and explanation (Nakhleh, 2008).

For the purpose of this book, an *image* is defined as a visual representation whose form bears a physical likeness to its referent, whether that referent is an imagined figure in a person's head or whether it is a process, organism, or other phenomenon in the world. This definition draws from Peirce's (1981) assertion that some forms of representation are *iconic*, or resemble physical aspects of what they represent, just as a photograph of a composite volcano looks like its referent, a composite volcano.

Along this continuum, *photographs* taken with a recording device appear to be the most realistic, followed by *drawings,* or visual representations created in the likeness of a referent. *Diagrams* are like drawings in the sense that they can eliminate or add visual information regarding their referents, but diagrams also include arrows, lines, and labels that show causes, processes, or relationships that are difficult to see with the unaided eye. *Maps,* too are abstracted images that locate an entity (e.g., a continent) at a specific *there* in relation to similar entities (e.g., other continents). Moving images can be abstract such as moving diagrams or realistic as in video footage, but they afford the same visualization of spatial relationships as they change over time. When added collectively, these five types of images—diagrams, photographs, drawings, moving images, and maps—comprised 24 percent of the total representations that the three teachers used in their classrooms, listed below in order of frequency.

Diagrams and drawings. If a picture is worth a thousand words, a diagram can be "worth ten thousand words" in science classrooms (Larkin & Simon, 1987). Unlike written words, which organize information word by word and line by line, diagrams and drawings display information according to location, grouping together aspects of a phenomenon in an organized and compact way. Because "there is often little about the surface features of physical phenomena that reveals underlying scientific entities and processes," Kosma (2003, p. 218) has recommended that teachers incorporate diagrams into their instructional repertoire when they are teaching scientific concepts that require students to understand *why* and *how* something occurs. Drawings likewise use of color, lines, and other features to emphasize targeted concepts while eliminating extraneous details (Topper, 1996).

In over one third of instructional episodes, Grace, Nancy Rae, and Tracy used diagrams or drawings from online sources, their textbooks, and whiteboard illustrations to explain core ideas in their curricula. These visual representations showed how rocks moved through the rock cycle, why solar and lunar eclipses occurred, how convection currents moved through the earth's mantle, how hurricanes formed, why equinoxes occurred, why tides occurred, how water moved through the water cycle, how tectonic plates interacted with each other, and more. A description from Tracy's instruction will show the role that diagrams played in conjunction with other forms of representation as she taught her students about the causes of sea and land breezes (See Figure 2.7).

After students measured and recorded the temperature of sand and water that had been warmed by a heating lamp, Tracy posted a photograph of a local beach on the Promethean board. To the right of the photograph, she drew an orange line on the whiteboard to represent sand and a blue wavy line to represent water. "Here's our sand over here, and here's our ocean," she explained as she pointed to each line. She then drew a yellow sun to the left of the orange and blue lines as she asked, "During the day, which one is heating up faster?"

Students told her that the beach was heating up more quickly, to which she responded by asking what was happening to the air above the beach. When students identified that it was becoming less dense and starting to rise, Tracy drew a red arrow moving upward from the beach. "Is it just going to be an empty space above the beach? We know that, yes, cold air sinks. So what's going to happen? Is it just going to go like this?" [draws a blue downward arrow over the water].

Student: The air from the ocean, it moves over where the hot air was.

Tracy: The more dense cold air that is above the ocean is going to move in and take the place where the warm air went up [erasing the vertical blue arrow and drawing a horizontal blue arrow that pointed toward the red arrow]. "So how is that going to make it feel?

Student: Windy.

Tracy: It's going to be very windy. So if we're on the beach right here (points to the photograph to the left of the diagram), and this is a nice sunny day (draws red sun at the top of the photograph), could we expect the wind to be coming from the ocean or the beach?

As she continued to solicit students' responses, Tracy also drew a diagram of what would happen to the same beach at night to the left of the original diagram.

In this example, Tracy drew from her students' experience with an observed, measurable phenomenon (the temperature of the sand and the water) to explain the causes of sea breezes and land breezes in the diagram. She included only essential elements in this visual representation: colored lines to represent sand and water, a red colored arrow to represent the direction of hot air, a blue colored arrow to represent the direction of cold air, a yellow circle to represent the sun, and a label that indicated a specific time: day. The image enabled Tracy to show how these various elements were spatially related to one another. Due to the spartan nature of the diagram, only the most relevant aspects of the phenomenon were communicated, for instance, the direction of movement as indicated by arrows and the temperature of the air as indicated by color.

While the diagram fulfilled this explanatory role, explicating *why* sea breezes were formed, the photograph grounded the image in an actual location, a local beach with a pier, to which Tracy pointed as she asked students to imagine themselves there. In this way, the two types of images worked together: The diagram grounded sea and land breezes in a theoretical space whereby students understood their mechanisms, and the photograph grounded the sea and land breezes in a physical space that many of her students had visited and enjoyed.

Photographs. Despite photographs' status as perhaps the "least informative" (Baigrie, 1996; cf. Pauwels, 2006) type of image among professional scientists, they were still a regular occurrence across the three earth science classrooms, appearing in about one fourth of all instructional episodes. In accordance with the idea that photographs are of little utility in science, Lee (2010) expressed concern that the number of photographs in middle school science textbooks has increased over the past 60 years at the expense of words and more explanatory images such as diagrams. He attributed this increase to textbook publishers' desire to move "toward the interpersonal" by emphasizing "familiarization" (p. 1120).

The three earth science teachers often used photographs to achieve the same function as Lee described in his study—namely, to ground students' knowledge of science in specific contexts or situations that were familiar to them, or to move "toward the interpersonal" by emphasizing the human dimension of science. Rather than viewing this type of familiarization as a source of worry, however, many researchers (e.g., Lemke, 1990) view it as essential for connecting students' own experiences and interests to the principles they learn in science. The example of instruction on sea and land breezes in the previous section provides one instance of how Tracy used a photograph to connect these breezes to a specific beach that was close to her school. Other examples demonstrate how the three teachers used photographs to convey a more personal dimension to earth science in at least three ways: (a) to show places that they or their students had visited; (b) to illustrate the impact that natural disasters can have on human life; and (c) to show people engaged in the act of data collection or analysis.

All three teachers used photographs of places they had visited to ground their discussions of general phenomena in specific locations. For instance, as Nancy Rae's students were discussing how ice can be an agent of weathering and erosion, she showed a photograph of glaciers she had seen while on a vacation to Alaska, sharing a brief story of her stay in a dog sledding lodge and describing how the glaciers had affected the landscape by carving valleys around her. Tracy used a photograph of a famous local tourist spot (a large rock) and asked her students to speculate how it had been affected by weathering and erosion, while Grace used photographs she had taken at a nearby beach to illustrate ways that local officials were trying to prevent erosion. In these cases and others, photographs served to ground discussions of general phenomena—glaciers, rocks, oceans, weathering and erosion—in particular places that had been visited by people in the classroom. All teachers had expressed a desire to take their students on field trips to these or similar places, but due to severe budget constraints, photographs were an economical alternative.

A second use of photographs entailed showing how natural phenomena had an impact on human life. For example, Nancy Rae's students viewed photographs of middle school students who were crouched in the halls, heads toward their lockers with textbooks over them, in response to a tornado warning. Similarly, Tracy's students viewed photographs of cars that had been flipped by tornadoes, while Grace's students discussed photographs of farmlands that had been devastated during America's Dust Bowl. As these examples indicate, photographs were used to illustrate the human impact of natural disasters, couching these disasters in terms of how they affect human life rather than in terms of scientific explanations.

A third use of photographs to move "toward the interpersonal" was the three teachers' use of photographs to show people—children and scientists alike—engaged in scientific inquiry.

For example, Grace’s students expressed interest in Mount Vesuvius after reading an article about pyroclastic flows produced by the famous eruption in AD 79. To extend their reading of the article, Grace displayed photographs of archeologists excavating the ash-covered site. In a different lesson, Grace’s students viewed a photograph of a person extracting fossils before they wrote journal entries as though they were paleontologists. Each teacher also showed photographs of children engaged in some type of scientific inquiry, often paired with an adult scientist.

In warning of the uses of photographs in science, Van Fraassen (2008) has warned against their seeming objectivity (cf., Lynch, 1990), recognizing that any photograph is the product of a selective choice to frame a certain aspect of something from a certain angle, at a certain magnification, with a certain grain. With today’s Photoshop capacities, the “truth claim” made by any photograph is even more suspect as any image could have been manipulated from its original view. Nonetheless, although photographs are not an uninterested depiction of an objective reality, they were used in the three teachers’ classrooms to ground their discussions in a particular type of reality—one that was experienced, lived, and constructed by humans. Photographs were used to turn discussions of generic volcanoes to discussions of specific volcanoes that people had visited; to turn discussions of scientific inquiry toward actual people who had conducted that inquiry; to turn explanations of erosion toward explanations of what formed this specific gully that was locatable on the planet. In this sense, photographs in earth science played an important role by grounding abstract processes in images that matched students’ everyday perceptual experiences.

Moving images. As several examples have indicated, even still images on a screen, board, or page can represent movement in several ways: by the gestures that are displayed over them; by their step-by-step construction as when Grace drew layers of dirt line by line to represent layering over time; by showing two images of the same phenomenon after a change has occurred; by actually physically moving the image itself; or by arrows that show direction of movement. Like still images, moving images held similar affordances in terms of helping students visualize changing spatial relationships, but they did so by embedding the movement within the representation itself. Like still images, moving images could be in an abstract explanatory space, such as colored cross-section diagrams of exploding volcanoes; or in a “real” space, such as several videos that showed children working with scientists to perform experiments with materials.

At times, a text’s ability to move, rather than to simulate movement through arrows or other markers, seemed to afford more accurate communication than still images. The diagram from Figure 2.8, which Grace used in her class, is an example of the difficulty of illustrating movement with still images. To help her students understand this diagram, Grace first asked her students to explain what might be confusing about it, to which one student responded, “It looks like there are eight moons.” Although each moon is necessary to represent a shape caused in part by a particular spatial position at a certain point in the moon’s revolution, Grace recognized the potentially confusing appearance of eight moons. To obviate the difficulty of communicating movement via a non-moving medium, Nancy Rae’s students manipulated a moving diagram of lunar phases online (http://www.harcourtschool.com/activity/moon_phases/). As this example perhaps obviously suggests, moving images are well-suited to provide clear depictions of movement, which are essential to understanding many concepts in earth science. The semiotic potential of digital mediums may be especially important in this discipline for this reason (Lowe, 1999; 2003).

Maps. Aside from John Snow, who used a map of neighborhoods in London to hypothesize that a cholera outbreak was related to a contaminated water pump, earth science boasts one of science's most famous examples of somebody who used maps as a primary means of scientific investigation and argument: Alfred Wegener (Giere, 1996). Wegener is credited for developing the theory of *continental drift,* the idea that the continents were once conjoined in a single ancient landmass called Pangaea. Although he presented many different kinds of evidence for this theory, Wegener (1966) wrote in *The Origins of Continents and Oceans* that "the concept of continental drift first came to me…when considering the map of the world, under the direct impression produced by the congruence of the coast lines on either side of the Atlantic" (p. 1). Wegener drew proposed maps of the world at different epochs as a way to both reason through his theory and to present arguments on behalf of his theory, which was not widely accepted until decades later when sonar technologies and other instruments enabled scientists to publish maps of the ocean floor and postulate theories of seafloor spreading.

Across all three classrooms, maps were used to teach Wegener's theories and to introduce later theories of tectonic plate movement. Tracy began her instruction on this subject by showing a map of the world and asking students what they noticed about the shape of the continents. After her students had identified that some of the shapes looked like they could fit together, Tracy introduced Alfred Wegener's ideas that the continents had once been joined together but had separated over time. To illustrate this process, students cut out different continent-shaped puzzle pieces (see Figure 2.9) and placed them together according to how they might once have fit. After piecing them together, students identified how the continents might have separated to their current position over time by sliding them apart to form a modern map of the world.

As Figure 2.9 indicates, Tracy's student placed Australia to the immediate West of Eurasia, and Antarctica immediately to its South. Tracy asked this student to look at the map of the world on the board, which showed the current positions of the continents, and to ask himself how the continents could have moved to their current position if they were once in the configuration that he had proposed. The student later changed his map to more closely reflect the original map of Pangaea that Wegener had drawn. After students had completed this activity, Tracy displayed a moving map of Pangaea on her Smartboard, pointed to a specific location on the map, and asked students to follow her finger as they watched that location on the map move throughout the different eras from its location in Pangaea to its position today.

Grace's students likewise read maps to learn about tectonic plates. They used lines of latitude and longitude to plot the location of earthquakes and volcanoes on an 8-inch by 11-inch map of the world. Students then connected the dots representing the earthquake followed by the dots representing the volcanoes. When they were done, students placed these maps on top of a similar-sized map of lithospheric plates. "Tell me something that you notice between each of these two maps…What do you see?," Grace asked. A student responded, "Mostly where there's volcanoes there's convergent boundaries."

Grace then asked the whole class to check that student's hypothesis by locating specific volcanoes on their paper maps and comparing them to the plate boundaries on the maps in their textbooks. Students identified that volcanoes occurred along convergent boundaries, although there were a few instances in Africa where volcanoes occurred at divergent boundaries. When asked what else they noticed about the volcanoes, students also noted that "they were close to the earthquakes." Grace then used their comments as a springboard to discuss the type of activity that occurs at lithospheric plates.

In these instructional episodes, the maps were conducive to promoting the kinds of spatial thinking that are central to geosciences, which include observing, manipulating, and interpreting the shapes and positions of objects and processes (National Research Council, 2006). In the first instance, to some extent, students engaged in the types of spatial transformations as Alfred Wegener when they speculated on how the continents might once have been joined based on their current shapes and their spatial positions. In the second instance, students used a different kind of spatial thinking: Rather than transforming shapes, they compared them—noting similarities between the locations of earthquakes and volcanoes, and noting similarities between tectonic plate boundaries and their mappings. Using these spatial data, students hypothesized that convergent boundaries were related to volcanic activity.

Maps were used to promote spatial reasoning about other subjects in earth science as well. For example, students looked at maps to answer questions such as, *Why do you think the Wright Brothers chose Kitty Hawk as the place to experiment with flying airplanes? Why doesn't Nevada get a lot of tornadoes? Why didn't our city get hit by the recent hurricane that hit a neighboring state?* Students synthesized the visual information provided by maps with their background knowledge (e.g., about the effects of uneven heating of land and water, the causes of tornadoes, and the causes of hurricanes) to formulate answers to these questions based on where places appeared in relation to certain topographical features.

In all, images—namely, diagrams, photographs, drawings, moving images, and maps—played a central role in communicating and constructing earth science, comprising one fourth of all representations. They were used in at least two ways: to engage students in the spatial reasoning required of earth scientists as they generate theories; and to communicate physical properties of phenomena in the universe. These properties were oftentimes visual properties such as spatial relationships, shape, and relative size, but to a lesser extent images also could communicate other physical properties such as heat (through colors such as orange to represent the hot mantle of the earth) or physical sensation (through arrows representing direction of wind). Different types of images were grounded in different epistemologies, or claims about how science is constructed and known—from abstract images, that grounded earth science as a discipline where invisible processes could be rendered visible and used to explain events on Earth, to photographs, that grounded earth science in the realm of students' everyday perceptual experiences.

Demonstrations, Labs, Measuring Instruments

Odom, Stoddard, and LaNasa (2007) maintained that middle school students often develop a more positive attitude toward science and perform better on assessments of scientific knowledge when they participate in instructional activities such as group experiments as opposed to solely reading textbooks or listening to lectures. As part of their commitment to "hands-on" science learning, Grace, Nancy Rae, and Tracy understood the importance of experiments, which comprised 7% of total texts. These experiments were conducted either as *demonstrations* performed by the teacher (often when the experiments were too risky or the materials were too expensive for each group to have its own set) or as *labs* performed by the students in groups.

A few descriptions of experiments will demonstrate how the teachers used them to further students' understandings of scientific concepts. Tracy's students put cold water in a clear pie tin that was elevated by two Styrofoam cups (see Figure 2.10). When the students put colored dye in the cold water, it stayed as a concentrated bead in the center of the water until students placed a cup of heated, steaming water beneath the pie tin, at which time the dye begin to rapidly disseminate due to the heated water that rose directly above the steaming cup.

One group of Tracy's students, when verbally explaining how this lab demonstrated convection, explained:

> *Student 1*: The cold water, when you first put the food coloring in there it stands still, but when you put the hot water under there it starts to move around because it's less dense…
>
> *Student 2*: …than the cold water.
>
> *Student 1*: It starts moving around. The food coloring will come around here [points to the edge of the pie tin] and it will start to come back in [points to the bottom of the pie tin] because it's getting colder.
>
> *Tracy*: What if you wanted to make it go faster?
>
> *Student 2*: Maybe put more hot water, put more hot water.

Tracy identified convection currents as a major concept in earth science, occurring in the earth's hydrosphere (as denser water sinks in the ocean), geosphere (as molten rock in the mantle cools upon approaching the crust), and atmosphere (as warm air at the equator rises, for instance). Although these processes ongoingly occur over large distances on Earth, texts such as labs enabled students to see how they worked on a smaller scale. In this lab, Tracy intended for her students to infer that the steam heated parts of the water, causing these parts to rise, spread out, and sink at the edge of the pie tin after it cooled down when moved away from the heat source. In this way, students were able to view an actual example of convection.

In another lab, Grace's students followed step-by-step instructions as they heated salol over a flame and then observed as what happened as it cooled at room temperature or cooled over an ice cube. In the first case, as the salol cooled more slowly, its crystals were large and observable, much like the crystals of intrusive igneous rocks that cool more slowly inside of the earth. In the second case, as the salol cooled more quickly, the crystals were smaller and harder to discern, much like the crystals of extrusive igneous rocks that cool more quickly above the earth's crust. Grace's students were instructed to draw pictures of the salol and to write an explanation of what they learned about the crystal size of intrusive and extrusive igneous rocks from participating in this lab.

Although these particular labs required qualitative observations, other labs required specific quantitative measurements as students read thermometers to ascertain temperature, a triple beam balance to determine objects' changing weight, a graduated cylinder to measure water displacement, and more. Scientific instruments, including those used for measuring different aspects of physical phenomenon, have a long history of occupying a central role in the sciences (Rosenthal & Bybee; 1987; Turner, 1998), themselves *texts* employed in the service of understanding changes in focal texts such as natural phenomena. Tracy and Grace both provided explicit instruction on how to read each measuring instruments—for example, instructing their students to move to eye level to read the amount of water in a graduated cylinder. When a group of Tracy's students wrote down inaccurate temperatures during a lab demonstrating the unequal rates at which sand and water heated and cooled, Tracy stopped the lab to provide explicit instruction:

> *Tracy*: If this [points to line on a thermometer] is 60, and this [points to another line] is 80, what would this be? [points to line exactly in the middle of 60 and 80]. How many degrees would that be?
>
> *Student*: 65.
>
> *Tracy*: Halfway between 60 and 80?
>
> *Student*: 70.

Tracy: So that means each of the little lines in between [60 and 80] is going to be worth how many degrees?

Student: 10.

Tracy: 10? So it's 60, 70, 80 90, 100, 110? [points to each line as she counts by 10].

Student: No.

Tracy: No, that's not going to work. If from here [points to line representing 60 degrees] to here [points to line representing 70 degrees] is 10 degrees,

Student: Two.

As this interaction suggests, at times experiments do not only require students to "read" water, sand, and salol as they note how these materials interact and react under different conditions. This act of reading is at times accomplished through measuring instruments, themselves texts in their own right whose meanings are not necessarily immediately evident.

At its core, earth science addresses the causes of many events and processes that occur on earth: winds, severe weather, tides, seasons, and more. Perhaps surprisingly, the natural world itself comprised less than one percent of teachers' total texts, including examples such as watching clouds or noting erosion on the school campus. Much of the time, however, the causes of physical phenomena are not readily discernable from the natural world alone, and many focal concepts are not accessible for direct viewing. In the words of Tracy, "You can't exactly go out and see the earthquakes, so you have to come up with things on a much smaller scale and make models, for earth science anyway." Labs and demonstrations served as a convenient alternative to the natural world by demonstrating cause-and-effect relationships on a micro-scale while maintaining aspects of the world's physical composition, requiring students to draw inferences about physical phenomena and to read a variety of instruments to support their conclusions.

Textbook Readings

While the three teachers consistently ranked *labs* and *demonstrations* as among the highest valued modes in individual lessons, across several lessons they ranked written words in the form of *textbook readings* as among the least useful mode. Tracy explained her decision to rank a lab more highly than textbook readings as she taught about convection currents:

> There's so much more to be communicated than just reading it. You have to be able to physically see and manipulate what's going on so that you can really understand what's happening because it's kind of hard to read in a description how convection currents work. You can even see diagrams in the book, but they're not moving, and a lot of kids have a hard time interpreting not just what they read, but [visual] graphics. So they need to be able to have other ways that they can access the information. And for most kids…the hands-on type stuff is what really helps them to get it.

As this example suggests, Tracy believed key aspects of convection currents—interaction between hot and cold mediums causing a particular type of movement—were better communicated through a mode whose properties included temperature and movement.

Nonetheless, written texts are central to scientific endeavors (Lemke, 1998), and as such teachers sought to provide students with explicit instruction on how to read scientific language. For example, to address the idea that scientific writing often classifies the world into taxonomies, Grace asked her students to look at the different sizes of headings in their textbook sections, to use these sizes to determine superordinate and subordinate categories of classification, and then to make graphic organizers of the textbook section that reflected their knowledge of these categories. To address the fact that much of scientific vocabulary involves nominalizations with multiple word parts (e.g., *compaction*, *divergent boundaries*), the three teachers stressed the learning of key prefixes, suffixes, and root words as students connected words they knew to words they were learning. For instance, Nancy Rae's students made a list of words they knew that began with *sub* and used their knowledge of this prefix to make inferences about what a subduction zone might be in reference to tectonic plates.

Although the three teachers provided explicit comprehension strategy instruction on these texts, however, textbooks were a relatively small percentage of their instruction. Consequently, it was not teachers' main objective to teach students how to regulate their thinking processes as they approached them. Instead, their goal was for students to develop rich understandings of scientific concepts. Although readings from the earth science textbooks at times helped their students to reach this goal, for much of the time, the three teachers obviated the challenges in textbooks all together by (a) writing, finding, and/or modifying alternative texts, such as interactive Smartboard presentations, which included student-friendly informational paragraphs, diagrams, and photographs about the target concept; or (b) presenting the same concepts in another way, such as through combinations of labs, videos, demonstrations, and verbal explanations of diagrams, drawings, maps, and photographs.

Rather than providing explicit comprehension strategy instruction on the textbook, a much more common approach to helping students understand textbooks entailed alternating between the reading of written words and the viewing of another type of representation. In other words, the teachers' primary approach for comprehension instruction was providing *conceptual redundancy* (Rapp & Kurby, 2010) by introducing the same concept through multiple forms of representation. The following example from Grace's instruction will illustrate how her instruction provided this redundancy.

After her students had watched a video about global winds, which included a diagram with moving arrows showing how different wind belts traveled across the earth, Grace asked a student to read about global winds from his textbook. “Near the earth’s equator, sunlight beats down almost directly,” the student began, “but sunlight slants down at an angle near the earth’s poles.” He continued to read about the how the uneven heating of the earth leads to differences in air pressure, which in turn causes global winds.

After students read a few paragraphs aloud, Grace asked a student to turn off the overhead lights as she shined a flashlight, or “the sun,” directly above her on the ceiling, which was divided into square tiles. She continued:

> I’m going to get [the light] to where it about fills in that ceiling tile. I’m going to tilt my flashlight. Now look at it. Is it filling up just one ceiling tile now? It’s like almost two ceiling tiles. If this were sunlight [points to the flashlight], and this were earth [points to the ceiling], would it be hotter at the first ceiling tile, or the second set of ceiling tiles?
>
> *Student:* It would be hotter at the first one.
>
> *Grace:* It would be hotter at the first one. Why do you think that?
>
> *Student:* It’s got direct sunlight.
>
> *Grace:* It’s got direct sunlight. What does that mean?
>
> *Student:* The sun shines directly on that one spot, and it’s not spread out.
>
> *Grace:* Right, it’s all concentrated in this one spot right here…Now if I were to take the sun and shine it on the earth, and remember, if this is the earth [puts her hand on a globe], the sun is going to be like way bigger than our classroom [extends both arms out as far as they can go]. Keep size in perspective here. So we’re just taking one little beam of sunlight. If I have one little beam of sunlight, shining on the equator [Grace shines the

flashlight on the equator], can you see that little circle right here? [With her index finger, she outlines the more concentrated circle of light that was in the center of the flashlight's larger circle of light]. See that circle shining on the equator? That's going to be direct concentrated sunlight right here.

After students noted that the light at the poles was less concentrated, and consequently the poles would not be as hot, Grace led students in a discussion regarding what they had already learned about ocean currents, which were caused in part by warm water rising at the equator and cold water sinking at the poles. She lifted her hands up above the globe at the equator, moved them out toward the poles, placed them down at the poles, and slid them back to the equator repeatedly to accompany the following verbal narration, co-constructed with students:

Grace: Warm air, warm water does what?

Students: Rises.

Grace: Rises, moves this direction, and the cold air and the cold water both do what?

Students: Sink.

Grace: Sink, goes back this way. Warm air, warm water,

Students: Rises.

Grace: Rises, moves this way,

Students: Sinks.

Grace: Sinks down. Do you see this pattern going on and on?

Student: It's like a cycle.

As this example illustrates, a targeted concept—in this case, global winds—was distributed across multiple forms of representation. Although the video and the demonstration could be considered forms of representation that supported students' comprehension of the textbook reading, Grace did not view her instruction in this way. Instead, she ranked the demonstration (shining the flashlight on the ceiling and the globe) as being the most helpful representation for building students' understanding of global winds; the video second; and the textbook last. She explained the purpose of the textbook: "The reading kind of sets it up and gives some background information that sometimes I'll forget to put in there. And it also just gives them practice reading a science book and science text because you know they are tested on this, and they do have to read it by themselves. But I like the doing stuff better than the reading."

Likewise, Grace mentioned across several interviews that students should know how to read textbooks, not because they were necessarily the best way to learn the targeted concept, but because students should develop the general skill of reading scientific language, which would help them to pass standardized tests and read scientific texts in the future. In terms of understanding global winds, however, texts that moved were better suited to convey the physical properties of this phenomenon and develop an understanding of how convection currents occur across the earth's hydrosphere and atmosphere.

When one considers that textbook readings comprised less 7% of the representations in the earth science teachers' classrooms, it becomes clear that textbooks were complemented (or obviated) by many other types of representation, as in this example of instruction on global winds. Therefore, a robust model of comprehension instruction in these classes would account for how concepts are distributed across representations. In this model, comprehension instruction would not simply involve one text: for example, by teaching students to preview their textbook section, identify its text features, and use these features to determine the organizational pattern of the section. Instead, it would teach students about ways of approaching their reading of the video, the textbook, and the demonstration by actively regulating their thinking processes as they built understandings of global winds across all of the sources.

Three-Dimensional Models and Objects

Five percent of the representations used across the three teachers' classrooms were *models*, defined here as three-dimensional objects whose properties were designed to explain a phenomenon in the universe (e.g., a clay likeness of a volcano), or *objects*, tangible manmade items whose properties were not purposefully designed to represent another phenomenon in the universe but that were still used to contribute to the instructional objective (e.g., a pencil used to represent a ray from the sun). This use of the term *model* is different than common definitions of scientific models (e.g., Grosslight, Unger, & Jay, 1991; Harrison & Treagust, 2000), which encompass many forms of representation, including algebraic equations, visual depictions, or any other representation that "abstracts and simplifies a system by focusing on key features to explain and predict scientific phenomenon" (Schwarzl et al., 2009, p. 632).

For the purposes of this book, the term *model* is applied to three-dimensional representations simply to enable comparisons across semiotic mediums—that is, to enable questions such as, *What does the a tangible item make possible that other forms of representation might not?* Like images, 3-D models can serve many purposes: to *depict* or *display* observable attributes, to *explain* aspects of a theory or phenomenon, to *predict* future phenomena, and to *generate* new theories (Griesemer, 2004). They can be *realistic,* designed to look exactly like a referent at a different scale (e.g., a wax likeness of Mount Saint Helens); or they can highlight some aspects of a referent to illustrate a theory or point (e.g., a three-dimensional cross-section of a generic volcano). They can serve as a template that brings an object into being (e.g., small-scale model of a weather vane that is later built) or an exhibition that brings the past to life (e.g., replicas of dinosaur bones).

Globes. The globe was the most common model used across the three classrooms. Like maps, globes are organized visual resources through which people make arguments that *this is there* (Wood, 2010). In addition to the characteristics that can also be found on flat maps, globes possessed unique affordances by showing these features on a tilted sphere that could spin and move in other ways. On a globe, directionality can extend beyond North, East, South, and West as it is recontextualized across multiple dimensions. For example, Grace pointed to Australia on a globe and asked her students why the people there did not fall off of the earth. When a student responded, “Because gravity pushes them down,” Grace countered, “Gravity doesn’t push them down; it pulls them to the earth. We’re being pulled toward the core.”

While speaking, she used a gesture next to the globe [fingers spread out, then pulling down and coming together] to indicate how humans are being pulled toward the core. In this lesson, Grace’s use of gestures over the globe showed students a different perspective of *down:* If people perpetually moved *downward,* they theoretically would continue to move past the center of the earth; instead, gravity could be considered relative to one’s current position and the center of the spherical earth. In this way, a globe was used to challenge common perceptions such as students’ everyday experiences of *down* (e.g., Vosniadou, Skopeliti, & Ikospentaki, 2005).

Nancy Rae, Tracy, and Grace used a globe to explain many other concepts as well. Placed near the front of each classroom, they each occasionally used it for ad hoc explanations by showing how it was tilted on its axis, by pointing to continents in different hemispheres and asking students what season this continent would be experiencing if they were the sun, by circling their fists around the globe to represent the orbit of the moon, or by moving the globe around another object that represented the sun. In Grace's class, pairs of students were each given a plastic globe and a marker. While his or her partner spun the globe, the other student tried to draw a straight line down the globe that inevitably ended up curved, an activity that Grace later used to discuss the Coriolis Effect. In an integrated mathematics and science lesson, Tracy's students tossed beach ball globes back and forth to each other, noting whether their right index finger landed on water or land each time. They then calculated the fraction, decimal, and percent of the earth's surface that was water based on this activity, and they compared their percentage to scientists' reported percentage of water on earth.

The affordances of globes were multifaceted throughout these lessons. Globes maintained the same facility as flat maps for communicating relative size, position, shape, and amounts, but globes also enabled these features to be grounded in diverse types of motion, physical action, and spatial orientation relative to other bodies. Using globes, students became agents of rotation, affecting the directions of global winds as they moved in particular patterns over the world's surface features. In Tracy's words, the use of globes during the lesson on percentages also enabled students "to actually see what's happening. And they would kind of start to laugh because as they were tossing [the globes], you know, you'd have one kid who would land on water like almost every time." As these examples indicate, globes directly fulfilled the three teachers' criterion that good earth science instruction should provide students with "hands-on" experiences with Earth.

Models and objects. Along with globes, the teachers used other types of three-dimensional models and objects to teach students about Earth and its processes. For example, in Grace's class, students used different colors of modeling clay to simulate rocks moving through the rock cycle (see Figure 2.11), applying heat and pressure to clay "sediments" to make metamorphic and finally igneous rocks. In Nancy Rae's class, students used a variety of edibles to represent a landfill: a fruit roll-up represented the lining at its bottom; a piece of licorice represented the pipe through which leachate could leak away; ice cream represented waste; chocolate syrup represented sludge; crushed graham cracker represented the clay soil that was packed on top prior to its closing; and green sprinkles represented grass that was planted over it. Before building each part of their models of both the rocks and the landfill, students viewed photographs of the actual items that their model components represented.

As a final example of an *object* used as a model, Grace asked her students to draw a cross section of a chocolate-covered cherry that had four layers: a cherry at its core, a pocket of clear liquid immediately surrounding the cherry, a thick white filling, and a chocolate shell. Students wrote one unique characteristic about each layer and completed a two-column chart in which they compared the characteristic of that layer to the corresponding layer of the earth. For example, when Grace asked her students to "give me a characteristic of the chocolate," one student responded, "it's solid," while another said, "thin." In the chart, Grace's students then compared this part of the cherry to the crust of the earth, explaining that Earth's crust was solid and thin compared to the rest of its layers but that its continental curst could be 50 km thick.

Unlike drawing or writing, models and objects could be both haptic and visual. Because physical processes of the earth can affect its visual appearance, a model's integration of the two sensory modalities enabled students to see (and enact) physical processes in way that demonstrated their interconnections, as when the application of heat and pressure led to a warped clay metamorphic rock. As the example of the chocolate-covered cherry indicates, one affordance of three-dimensional, tangible objects is that aspects of their physical composition can be used to represent the physical composition of its referent—something not afforded by representations on pages or screens. In this case, students felt how a solid was different from a viscous white filling.

Although each model or object afforded the communication of different aspects of its referent, it was also limited in what it could express. These kinds of misrepresentations, and/or representations whose similarities to and differences from its referent are not clearly explained, can cause students to develop ideas about the world that differ from those accepted by scientists (Adadan, Trundle, & Irving, 2010). Even though the clay model provided students with a visual and tactile example of how pressure shapes rocks, for instance, the degree of heat and pressure that students can exert on clay is different from the degree of heat and pressure exerted on a rock to cause it to warp.

Likewise, although a chocolate-covered cherry filling and the mantle may both be viscous, the nature of their viscosity and other tactile properties are also different; and although chocolate may be a solid, it is a different type of solid than the rock that comprises the earth's crust. In this sense, models in science can miscommunicate just as much as they can communicate, leading to misunderstandings as well as understandings. For this reason, Grace's instruction included explicit discussions about how the object (cherry) was similar and dissimilar to what it signified, addressing both students' knowledge of physical phenomena and their knowledge about the nature of scientific representation.

Reading Practices Specific to Earth Science

As a whole, earth science was the most semiotically diverse discipline studied, one wherein teachers regularly integrated a variety of modes to communicate core disciplinary concepts. Students regularly learned from images and gestures, built models, or recorded observations taken from measuring instruments—all in the service of building scientific understandings. How might reading be reconceptualized when *text* is just as likely to be the interacting materials in an experiment as it is to be words in a textbook? A few examples from the teachers' instruction suggests diverse modes required particular kinds of reading practices, including *reading from an angle, physical manipulation,* and *considering scale.*

Reading from an Angle

Because earth science regularly integrates a wide variety of visual texts whose spatial properties are significant to understanding key concepts, the physical angle at which students read texts often mattered in this discipline. Although teachers also encouraged their students to look at texts from a different physical angle in mathematics (particularly in geometry units), students were asked to read from a different physical angle in earth science more than in any other discipline.

Several examples will demonstrate how the angle at which students were positioned in relation to a text was vital to whether or not they could draw scientifically acceptable inferences. During a lesson on lunar phases, Grace's students sat in the center atrium of their school, from which all halls in the school emanated, as Grace held a ball that was half yellow and half black. "We're going to assume that the very end of that seventh grade hall [points to the doors at the end of one hallway], that parking lot, is where the sun is. So which way should I orient this ball?" After students explained that the ball should be oriented so that the yellow part of the ball was always facing the seventh grade hall or the sun, Grace told students that they were the earth and that she would walk the "moon" (represented by the yellow and black ball) around them. As she stood at different points in her orbit, students drew what they saw of the ball from their vantage point on earth—in effect, simulating the phases of the moon.

At one point, when a student tried to move a few feet away from the rest of the class so he could draw on his paper, Grace directed him back to the center of the atrium, warning him that he would not see the right view of the moon unless he was with the other students. In this case, the students' spatial position relative to the ball influenced whether they saw a phase of the moon that was consonant with scientists' descriptions of lunar phases. If students physically moved their bodies at a different angle in relation to the text they were reading (the ball), their view would have given them an inaccurate picture of the moon as it stood in a particular point in time and space as part of a predictable sequence.

After returning to the classroom, students were asked to label a diagram (see Figure 2.8) and to paste a photograph of the moon on each phase. To prepare students to complete this task, Grace had posted a large copy of this diagram on the board with a circle representing the sun to the right of the diagram. Grace first asked them to notice the angle at which the diagram was made. She and her students held the following interaction:

> *Grace*: The moon looks exactly the same in all of those pictures [points to the different phases of the moon on the diagram]. Tell me what perspective this drawing was made from. So where was the artist when he was drawing this? Where was he? What do you think?
>
> *Student*: He was standing on earth.
>
> *Grace:* So he was standing on earth when he drew this?
>
> *Student:* No.
>
> *Grace*: No, okay, so he's not on earth. So where was the artist when he drew this picture? What perspective is this drawing from? So where did he have to be, or she—I don't know if it's a he or she—to get this picture?

Student: Like really high in space above it all.

Grace: Really high in space. It's like they went to the North Pole, took off from the North Pole, flew way way way out, millions of miles away [put index finger on the earth of the diagram that is taped on whiteboard and moves finger out as she steps several feet away from the whiteboard], and then looked back [turns around to face the whiteboard again] and you could see the sun [still several feet away in her position in "outer space," she points to the sun pasted to the right of the diagram], and you could see the earth [still several feet away, she points to the earth on the diagram]. This is like time lapse photography where they waited 28 days and took pictures of the moon. That's why the moon always looks the same, because you always have half of the moon being lit by the sun [moves body back to whiteboard and points to the moon halves that are lit by the sun]. So, they can always see from out in space, this half is lit up and this half is not [points to the lit half of one moon and its dark half]….Now I want you to transport yourself to earth. You're standing on earth. Take your finger or take your thumb. You see how there's this dotted line right here [moves index finger around the dotted line on the diagram]. That's the moon's orbit around earth….I want you to take your thumb, and I want you to cover up the part that's outside of the dotted line. Right here [places her finger on the outside of the dotted line over one moon in the diagram]. So if I was standing on earth, and I were to look out, I would see what is not covered. What do you see when you're looking at that?

At this point, the students proceeded to physically lift up their own individual diagrams, cover up the part of each moon that was outside of the dotted line with their fingers, look at that moon from the position of the earth on the diagram, and paste the corresponding photograph of the moon that matched what they saw when they looked at the moon from the position of the earth.

Throughout this instructional episode, Grace emphasized the physical angle at which lunar phases were represented in several ways. First, she drew students' attention to the angle at which the maker of the diagram had been (theoretically) viewing the phenomenon that s/he represented. Second, she compared this angle "from way way way out in space" to the angle that people would assume from the earth when she asked students to pick up their diagrams and read them from a particular angle (e.g., looking from the earth at the center of the diagram out toward the part of each moon that faced the earth).

Grace and Tracy further encouraged students to read texts from different angles when they did various labs with water (e.g., poured colored salt water into a plastic container of clear water; placed a heat source underneath a clear container of water with dye). In order to see how the denser saltwater sunk, or how warm water caused the dye to spread out more quickly, students were instructed to look at the water from different angles: from above, from the side, and at eye level with the water container. In a lesson on ocean topography, Tracy thought the diagram of the ocean floor in her students' textbooks was "confusing" because "they're showing you kind of like you're looking from up in the air…so you guys are getting this diagonal look" that made the continental shelf look more slanted than it should have been relative to the other features of the ocean floor.

Tracy projected the textbook diagram on the overhead and moved her hands (palms facing toward each other about eight inches away) down toward the diagram at a diagonal angle to show her students the vantage point from which the ocean floor had been viewed as it was portrayed in that diagram. To provide students with a different perspective of the ocean floor, Tracy drew an image of the floor “straight on,” pointing to each aspect of the diagram and comparing it to her drawing. Tracy and Grace also taught their students to read various measuring instruments by looking at them from eye level in order to obtain accurate readings.

These lessons represent a few instances in which the earth science teachers encouraged students to attend to the physical angle of texts by (a) asking them to note the angle at which the text was made; and/or (b) asking them to read texts from different vantage points by changing the position of their body in relation to the text. In all, depending on the nature of the text that was being studied and the purpose for which they were reading it, earth science teachers engaged their students in questions such as the following: From what vantage point was this image made, and how would it look from a different vantage point? How would this text’s appearance be different if we viewed it from another angle? How can we synthesize the information we learned about the text by viewing it from this angle and by viewing it from that angle?

Physical Manipulation

In earth science, students were required to physically manipulate focal texts order to derive scientifically acceptable understandings of the texts’ meaning. In one sense, texts in all disciplines require students to physically interact with them in particular ways. For example, a novel in English often requires students to open the cover and turn pages if they want to gain understandings of it. In earth science, however, this type of physical manipulation was more varied and, if done incorrectly, could lead to inaccurate conceptions of the studied subject.

A few examples will illustrate how texts required specific type of physical manipulation in order for them to portray conventionally accepted scientific concepts. To teach the concept of seafloor spreading, Tracy asked each of her students to divide a piece of paper into twelve even sections, numbered 1 to 6 twice (see Figure 2.12). Each section represented rock that was formed during a different time period: Rocks labeled *one* were formed first; rocks labeled *two* were formed second, and so forth. Students were instructed to fold their papers in half, place them inside the cracks of two desks, and pull them out slowly, representing how magma continually pushes out of rifts in the ocean floor and forms new rock with the oldest rocks being farthest away from the rift. If the students had performed this action in a nonstandard way—such as beginning from a fold that was labeled *4* instead of *6*, then the text would have communicated incorrect concepts about seafloor spreading.

As a second example, in a demonstration on lunar phases, Nancy Rae placed a lamp, representing the sun, in the middle of her darkened classroom. She gave each student a Styrofoam ball representing the moon and told students that their heads represented Earth. Students were instructed to hold the ball at eye level, facing the sun, and then to rotate their bodies around in a circle, with arm still extended and ball still at eye level. The shadow that fell and rose on the Styrofoam ball represented the various phases of the moon. If students turned in the wrong direction; if they held the ball in such a way that they could not see the shadow; or if they turned their bodies too far at any given phase, they would have seen a depiction of the moon that did not match the appearance of the moon at that phase. In this way, students' physical movements and interactions were central to building scientifically-accepted understandings of lunar phases.

Understanding Scale

In earth science, teachers addressed processes that occurred over millions or even billions of years as well as processes that occurred over vast distances. Consequently, Grace, Tracy, and Nancy Rae worried that they did not often sufficiently communicate the scope of what they were talking about—that is, although concepts such as the formation of the solar system, water on

Earth, and billions of years might be communicated through images, words, or numeric timelines—oftentimes these representations were relatively ineffective at communicating the scope of time or space involved with each phenomenon.

To counter this limitation, Nancy Rae, Tracy, and Grace planned activities with the express purpose of communicating the idea of scale. For example, Grace began a lesson on geologic time by using gestures to represent different segments of time. She and her students separated their arms as wide as they would go to indicate the whole of geologic time; then moved their hands closer together to indicate eras; then moved their arms closer together to indicate periods; and repeated the process to represent the smaller time segment of epochs. Grace then divided the class into pairs and assigned each one a different period or era: Precambrian, Carboniferous, Triassic, Quaternary, and so forth. For each period or era, students drew illustrations and wrote bulleted lists outlining the major events that set this time segment apart, placing their work on a timeline where each centimeter equaled two million years.

The Quaternary Period, our current period during which human life came into existence, was represented by eight tenths of one centimeter, whereas other periods averaged over 15 centimeters. When Grace unrolled a piece of paper that was over 20 meters long, extending throughout the entire length of the sixth grade hallway and representing the Precambrian Era, students responded with remarks such as, “Wow!” “Are you serious? You’ve got to be kidding me,” and “That’s impossible!” When compared with the 8/10 centimeter that comprised the era when all of human life appeared, the students were visibly impressed that the Precambrian Era was so long. When asked about the purpose behind this activity, Grace explained that it was “impactful,” elaborating,

> The purpose was to really demonstrate that, oh look, there are humans in this one little bitty centimeter, and here's the rest of geologic time, that's really really really long. I think it was very impactful when they were sitting in the hall against the wall, and um, I unrolled that looong strip of paper, and they saw how long it was, but then saw humans were only a centimeter wide—no, it was eight tenths of a centimeter, it wasn't even a whole centimeter—that humans were itty bitty compared to the rest of geologic time.

Other representations, too, were designed to be perceptually impactful, such as when Grace and Tracy's students stood outside, with different bodies representing the planets in the solar system, as they figured out how far they should stand from each other if each meter represented 50,000,000 km, and they extended throughout the entire length of the school property. Grace's students then created a scaled model of the solar system representing size instead of distance when planets less than the size of a paper-punched hole were compared to a much larger sun (See Figure 2.13). Nancy Rae and Grace's students both reduced several liters of liquids, representing all of the water on the planet, to a few drops of water representing the amount of drinkable water on the planet that "wasn't even a sip," to use Nancy Rae's words.

Because teachers' other texts—such as gestures over a photograph representing centuries of weathering and erosion or a one-inch circle on a diagram representing the sun—did not necessarily communicate the magnitude involved with the different objects' properties, teachers built in activities such as these ones to remind students of the scales inhering in earth science as compared to students' everyday perceptual experiences. As part of reading in earth science, teachers hoped that their students would remember these scales when making sense of diagrams, drawings, gestures, and other texts.

In sum, reading in earth science was distinct from other disciplines in many ways. First, it was commonly tied to physical action as students repositioned their bodies at different angles in relation to texts or as they physically manipulated labs and a variety of models. Not only were students' hands and bodies physically active in relation to these texts, but these texts themselves often underwent physical changes, not appearing the same as they did during students' first view of them. Reading at times entailed noting these changes as students used a variety of models, labs, and other texts to investigate answers to essential questions that required them to describe a changing Earth and as they considered the scope of the phenomena that these texts were intended to convey.

Possibilities for Reading Instruction

Given the specific nature of texts and reading practices in earth science, what kinds of reading instruction might be provided on texts in this discipline? This section outlines ways that different time-honored comprehension strategies can be modified and applied to multimodal texts. The purpose of section is not to describe step-by-step instructional activities to build students' reading comprehension, but instead to describe general approaches to ways that earth science teachers might support their students in actively reading a variety of multimodal texts as they regulate their thinking processes in regards to these texts.

Predicting and Checking Predictions

Predicting is a staple of scientific inquiry in earth science as practitioners use available knowledge to predict the impact of different types of human activity on the earth, to predict the occurrence of different natural disasters occurring in particular areas, and more. In earth science classrooms, students also make predictions as a core component of scientific inquiry. Each teacher, for example, required students to predict outcomes of experiments, including projecting how those outcomes would change if particular variables were changed, and to check their predictions after conducting the experiments.

One could imagine students justifying their predictions about many different types of multimodal texts as well. For example, recall Grace's students who huddled in the atrium of the school, their bodies collectively representing the earth, as a half-black, half-yellow ball represented the moon while Grace moved the ball in an orbit around her students to illustrate lunar phases. As Grace stood in the position where her students observed a full moon, she could ask her students to predict what would they would see when she moved halfway around the orbit—in essence, standing on the other side of her students where they would only see the black half of the ball representing a new moon. This type of prediction would require students to engage in spatial reasoning, identifying patterns in lunar phases as they predicted what the moon would look like at the opposite point in the orbit.

As another example, consider the rock models that Grace and Nancy Rae's students made as they subjected clay to various stages of the rock cycle. In the sedimentary rocks, layers and individual rock particles were still visibly distinguishable from each other. At that point, students could make and justify predictions about what would happen to the appearance of the sedimentary rock models after they had been subjected to heat and pressure and later even "melting," becoming an igneous rock instead.

Tracy's students used photographs of land features to predict what these features would look like after centuries of further erosion, while Grace's students used their knowledge about the heating of sand and water to predict the direction that arrows would point on unfinished diagrams of sea and land breezes. Similarly, Grace and Tracy's students predicted the immediate weather based on the types of clouds they observed, current temperature, and reports of humidity. Predicting, when used across multimodal texts, can require students to use background knowledge to project how a variety of visual, tactile, or natural texts should or would appear in the future under certain conditions, a strategy that has the potential to increase comprehension as well as engage students in scientific thinking (cf. Alvermann & Wilson, 2011).

Questioning

Like predicting, questioning is also at the heart of scientific inquiry, driving the development of explanations, theories, and innovation. Curiosity and inquiry are core scientific habits of mind, ones that the three teachers stated were central to their instructional goals. When asked what she wanted her students to come away with in earth science, for example, Nancy Rae responded that she wanted them "to have a curiosity, to know how things work, to have an excitement about exploring and learning and seeing how things work. And having the desire to try and go find the answers."

As students make sense of the natural world and the objects within it, students can develop empirically testable questions about these "texts" and devise methods by which possible answers to these questions can be generated, including methods that involve both physical experimentation and drawing from available scientific research. For instance, a unit might begin by showing different samples of soil (clay, loam, sand) and asking students to write questions based on their observations of these samples, such as *Why do soils feel different? What are different soils used for? How are different types of soil formed?,* questions which would form the foundation for the forthcoming unit of study as students sought answers. Rather than positioning students as passive responders to others' questions, student-generated questions can require students to assume roles as investigators.

Alvermann (2004) argued that questioning in science can serve other functions as well. Students can engage in self-questioning as they read any form of text—from monitoring their comprehension and clarifying the content of their textbooks, to wondering why a lab turned out the way that it did, to asking extension questions after reading images and gestures, as in the case when Grace's student asked her if sea and land breezes could move in a North to South orientation after she had used gestures to show Easterly and Westerly sea and land breezes. An activity as simple as asking students to write and discuss questions that they still have after reading any type of multimodal text (e.g., lab, gestures) can help students practice this strategy. Like predicting, questioning is a comprehension strategy that requires students to assume an active approach to texts while engaging them in the types of inquiry practiced by earth scientists.

Making Connections

Scientific inquiry likewise requires making connections, including links to established research and theories and connections across phenomena in the physical world. Perhaps not all connections, however, have the same potential to engage students in the kind of connections practiced by scientists. For instance, when one of Nancy Rae's students said that the splitting of the tectonic plates reminded him of his parents' divorce, this experience had limited potential to engage him in thinking about divergent, convergent, and transform plate boundaries, which was the purpose of the lesson. What types of connections did teachers use to help students develop understandings that they hoped would further their understanding of content?

In earth science, teachers oftentimes directed these connections toward students' physical sensations: what they felt when they walked through fog, how their ears popped when they flew in an airplane or surfaced from sitting at the bottom of a swimming pool, how the temperature of the sand felt on their feet on a hot day as opposed to the temperature of the water on the beach, how the air felt on their feet after opening a refrigerator door, how the air felt when they walked upstairs in their homes on a hot day, how their bodies continued to move forward after somebody slammed on car brakes, how the outside of a cold glass of Coke felt on a hot day, and so forth. Vacations were also a rich source for connections: Students made connections to houses they had observed on the beach that had been built on stilts to prevent wind and water erosion, to science exhibitions they had visited, and to land formations they had seen while hiking or camping with their families.

Students also made visual connections. For example, they compared the appearance of an image or lab at one point in time to its appearance at a later point in time such as a moving map of Pangaea and a sugar cube that evaporated in water. Students also compared the appearance of different types of physical phenomena such as the shape of a cinder cone volcano versus the shape of a shield volcano and the appearance of a sedimentary rock versus an igneous one. A third type of visual connection entailed comparing the angle at which one text was made to the angle at which another text was made.

At times, these visual and spatial connections were accomplished through physically layering one text on top of another, such as when Grace's students placed a map of volcanic activity over a map of tectonic plates. As another example, Grace's students viewed a moving image of a circle (the moon) revolving around a larger circle (Earth). Grace stopped the video as the moon was in mid-orbit, placed a globe over the circle representing Earth, and asked students in what direction the globe should be oriented, making connections between the two-dimensional diagram and the model in three-dimensional space. In all, making connections between in earth science could entail noting the visual similarities between texts, at times even placing the texts next to each other to make these connections more salient, coupled with connections to students' experiences with the physical world.

Determining Salient Information

As part of making inferences about why phenomena occur, scientists draw lines between what is relevant to the case at hand and what they view as extraneous noise (Pauwels, 2006). Students, too, can practice this line of thinking by learning the comprehension strategy of *determining salient information* as they read a variety of texts. Several instructional activities have been recommended to help students distinguish the big ideas in printed texts, including activities that direct students' attention to headings, subheadings, and other text features (e.g., Duke & Pearson, 2002). Even when texts are not printed, however, this strategy can still direct students' attention toward relevant aspects of non-print texts.

Consider a "rainbow density lab" that Tracy's students conducted wherein they placed several teaspoons of salt in water with blue dye, one teaspoon of salt in water with red dye, and no salt in water with green dye. When students poured the water into a graduated cylinder, the blue water sank to the bottom while the green water remained on the top. Grace's students conducted a similar lab in which a jar of hot red water was placed, with its open top facing downward, on a jar of cold blue water. Instead of mixing with the blue water, turning in it purple, the red water for the most part remained in its own jar, illustrating the principle that cold water sinks while hot water rises.

In both instances, the labs illustrated the principle that denser water—whether it is cold or characterized by high salinity—sinks, while less dense water rises. In the first case, *salinity* was the salient feature that determined the outcome of the lab, whereas in the second case, *temperature* was the salient feature. *Color,* in both cases, enabled students to view layering, but it did not affect the formation of the layers. In identifying *why* these (and other) labs resulted in a particular way, students can be asked to distinguish the salient from the non-salient features. In other words, they could articulate that the water rose not because it was *red,* but because it was *warm;* or that water did not sink because it was *blue,* but because it was diffused with the greatest amount of *salt.*

The strategy of *identifying salient information* can be used to help students understand other types of non-print texts as well. In photographs of phenomena such as rocks and volcanoes, for example, teachers can ask students to identify the salient from non-salient features as scientists develop classifications. In this case, the shape of volcanoes is salient in determining their type, but the shape of rocks is not usually salient. As students learn that some aspects of a text are more relevant than others, they can approach a variety of texts—from labs to textbooks to images—with selective discernment as they decide which aspects of the text they should attend to and which aspects of the text are relatively minor in importance.

Summarizing

Closely tied to the strategy of identifying relevant information is the strategy of *summarizing* as students synthesize and explain the big ideas from the texts that they have read. Just as the texts that students read in earth science assume a multitude of forms, their summaries of these texts can assume different representational forms as well. Grace and Nancy Rae's students both summarized the causes of lunar phases, for example, after participating in an activity in which they revolved a Styrofoam ball (the moon) around themselves (the earth) in a darkened room with a light bulb in its center (the sun). Instruction in summarizing can entail asking students, "What are the important features of this phenomena, and what would be the best way to summarize them?," providing students with representational choices just as scientists have representational choices in communicating their observations and conclusions. In the case of lunar phases, where the moon is constantly changing shape (crescent, half, gibbous, and so forth), a diagram indicating the earth and moon's relative spatial position at each phase might serve as an apt summary, one whose affordances communicate relevant properties—in this case, shape and spatial position—more precisely than words.

How might earth science teachers provide explicit instruction on constructing visual summaries? Baigrie's (1996) discussion of scientific images points to possible answers to this question. He argued that effective visual scientific communication requires the elimination of non-essential visual details by focusing on salient details, at times adding arrows, labels, and other features that show interactions or effects. Consider the example above where each teacher's students viewed photographs of different types of volcanoes in natural settings that included clouds, lightening, tumbleweeds, trees, a sunset, and so forth. A visual summary that explained volcanic types might eliminate these non-essential details, focusing only on each volcano's shape with perhaps a written summary of how it ejects particular types of lava and how it is formed.

Earth scientists synthesize information from a variety of sources—the natural world, technological instruments' renderings of the natural world, written texts, diagrams, and more—as they build understandings of natural phenomena and subsequently seek to communicate these understandings in the clearest and most efficient way possible. Likewise, the strategy of *summarizing* requires students to identify efficient ways to communicate important features of the phenomena they are reading about, a task that can promote comprehension as well as engage students in the types of communication used by practitioners in the field.

Inferring

Inferring, too, is not only a comprehension strategy recommended by literacy specialists, but also a practice that is central to the work of earth scientists as they develop hypotheses. As a means of inducting students into scientific practice, teachers can explicitly model *inferring* as a comprehension strategy that can be applied across multiple types of texts. Grace's students, for example, made inferences about why layers and chunks of rock could still be seen in photographs of sedimentary rocks, while Tracy's students made inferences about minerals after performing a series of tests on them.

Inferring in earth science was related to but distinguishable from *observing,* a distinction that Grace tried to emphasize. In a lesson on how scientists use indirect evidence to make inferences about the center of the earth, Grace asked her students to use observations of two small, black, sealed plastic containers to make inferences about their contents. When Grace first asked students to record observations, they instead made inferences, such as, "It's a battery."

Grace clarified that "it's a battery" was not an observation and asked students to define observation, which one student described as "when you use your five senses to write down whatever its features were." *It's a battery* was a conjecture, not an observation, Grace explained, because the students did not use their five senses to observe the inside of the container. After this clarification, students responded to the task by naming observations such as, "It's kind of heavy and makes a clinky noise when you roll it." In this way, Grace required her students' inferences to be first grounded in articulated, specific observations.

Grace also required students to notice how scientists might use the same data to draw different conclusions. In this lesson, while some students believed a black sealed container was filled with flour, others maintained it was filled with dirt. Both inferences were grounded in available data of what the container felt like when shaken, but neither inference was ever substantiated. (Grace did not let them open the container much like scientists have not seen the center of the earth.) In the same way as Grace's students drew different inferences about the same container, scientists have historically observed the same phenomenon—the changing moon, for example—and have generated different explanations about it. Likewise, instruction in inferring in earth science can include explicit discussions about how students can generate different explanations or conclusions about the same text.

Physical Action

In earth science, reading was not was only a cognitive process but was a visibly physical one as well. While all reading requires some type of physical interaction with texts, such as directed eyes toward a page, these physical interactions were pronounced and varied in earth science as students moved their bodies in relation to what they were reading in order to see the text from a different view. Part of reading instruction in earth science, then, might include explicitly teaching students about repositioning their bodies in relation to certain types of texts. For instance, students can be explicitly taught how to read a variety of measuring instruments at eye level, or how to read labs from certain angles, such as when Grace and Tracy's students viewed convection currents by looking down on them and by looking at them from eye level. In a similar vein, students can consider how the physical angle from which a phenomenon is portrayed shapes the readers' view of that phenomenon, and they can speculate on how it would look from a different angle, much like Grace asked her students to do when viewing a diagram of lunar phases as they appeared from a point in outer space.

Reading in earth science entailed other types of action as students manipulated texts by cutting them, pressing them, rolling them, pulling them, hitting them, heating them, cooling them, scratching them, turning them in a circular motion, and otherwise moving them. If students did not precisely perform the specified physical action in relation to the text—if they did not cut it in the right place or the right way, if they did not press it with enough force, etc.—then the text would not communicate the properties it was intended to convey. Reading instruction in earth science, therefore, can encompass modeling the specific physical actions for students to take in relation to texts. This type of reading instruction can also draw students into thinking about how they might physically act on texts themselves through questions such as, “How might this text (e.g., a chocolate-covered cherry representing the layers of the earth) appear differently if we manipulated in it a different way (e.g., cut it in a different place)?”

More broadly, reading instruction can also entail explicit discussions regarding how the properties of the focal text are affected if the text is manipulated in a non-standard way. For instance, if a few of Nancy Rae or Grace’s students overextended their Styrofoam balls (moons) by moving them too far along the orbit in the demonstration of lunar phases, students could discuss why they saw non-standard views of the moon. Likewise, in a lab whose outcome was unexpected, students could discuss how their physical manipulation of the lab materials might have influenced the results. In these ways, students can be brought into conversations about connections between *physical action* and *reading* in earth science, a field wherein many focal texts communicate certain properties only after they have been handled in a particular way.

Representational Practices Specific to Earth Science

In earth science instruction, written words comprised only 37 percent of total representations. How did students communicate their understandings of these texts in return? As shown in Figure 2.14, students were largely assessed through various genres of written words, and to a lesser extent, various types of images. A comparison of the modes used for instruction

(Table 1) to the modes used for assessment (Figure 2.14) therefore highlights a general trend in earth science: Students frequently read and made sense of a variety of modes such as images, gestures, and labs, and then translated their understandings of these modes to written words.

Recommendations for representation instruction in this discipline may therefore need to account for the types of semiotic transformations that occur prior to writing. One example of Grace's writing instruction, taken from a lesson in which her students wrote in response to the prompt *Explain what happens when land and water heat*, will serve as a starting point for a discussion of how earth science teachers might help their students translate from one mode to another in the process of producing a final written text.

Grace introduced this writing prompt at the beginning of the lesson, explaining that it was her overall goal for students to be able to write an answer to this question by the end of the 90-minute period. Students prepared for this assignment first by finding out what happens when land and water heat. Specifically, they recorded the temperature of the air above a container of sand and a container of water as it was heated by a powerful lamp. Grace asked her students how they could record what happened to the water and sand.

Student: Make a chart.

Grace: By making a chart. Exactly. What kinds of things would we need on our chart?

Student: The temperature of the water and the temperature of the land.

Grace: Temperature of the water, temperature of the sand, anything else?

Student: The time.

Grace: And the time. So let's make a chart. So on your notebook paper, let's do our time. And we're going to measure our time in what?

Student: Minutes.

Grace: Minutes. Because we're not going to do this for hours, unless you want to stay here all night long in science.

Student: I do.

Grace: Oh, I don't. [Grace begins a three-column chart on the board by writing the heading *Time (min)* over one column.]

Grace: Time, and then we need the temperature of the sand. Now do scientists use degrees Celsius or degrees Fahrenheit?

Student 1: Fahrenheit.

Student 2: Celsius.

Student 3: Both.

Grace: Celsius. That is the international system of units, or metric system. [Grace writes *Sand* $^{\circ}C$ as a header for the second column of the chart.] And we need water, also in degrees Celsius. [Grace writes *Water* $^{\circ}C$ as a header for the third column of the chart.] And I'm putting our units up here [points to top of each column] so I don't have to write them over and over again, although everything in that column [runs hand down column titled *Sand* $^{\circ}C$] is degrees Celsius and everything in that first column [points to column titled *Time (min)*] is in a minute.

Students recorded the temperature of the air above containers of sand and water for 20 minutes. The containers were heated by a powerful lamp that was turned off at the ten-minute mark. Grace asked her students which type of graph would best represent their table that recorded temperature and time period. A student identified a line graph would be best, to which Grace responded, "You are exactly right. Any time you have something changing over a period of time, that's going to be your line graph." After students identified which would appear along her x and y axes (time or temperature), Grace drew an x and y axis on her Smartboard whose background looked like graphing paper.

Students identified that each interval for the x-axis should be *one minute*, but some began to make graphs by placing numbers in the spaces of their graphing paper rather than on the lines. In response, Grace said, "Everyone look up here, important. Do you write zero on the line, or in the space?"

Student: On the line.

Grace: On the line. That way you can go exactly up and over your lines [moves index finger up one vertical line and over one horizontal line as though she were finding a coordinate point]. So zero's on the line, one is on the line, two is on the

Student: Line.

Grace: Three is on the

Student: Line.

Grace: [Moving across the x-axis, she writes a number on a vertical line for every number she calls out to the students]. Okay, I think you get it now.

Although Grace's students were in consensus that *1 minute* was a sensible interval for the X-axis representing the *time* that the sand and water heated and cooled, they held different ideas about intervals to put on the Y-axis that represented the *temperature* of the sand. Grace addressed this difficulty in the following interaction:

Grace: What's the lowest temperature we have up here? What is our lowest temperature?

Student: 22 degrees.

Grace: 22 degrees right here [points to 22 on three-column chart]. What's our highest temperature?

Student: 29.

Grace: 29, very good. So we have a range of 22 to 29 degrees. Should we count by 10s?

Student: No.

Grace: If we counted by 10's, we'd have 0, 10, 20, 30, 40, 50. We'd put everything between two lines [puts two palms, face down, toward each other]. Would you be able to really see some changes?

Student: No.

Grace: Look at this data [points to chart]. Raise your hand and let me know what you think we should count by.

Student: Fives I think.

Grace: So if I count by 5's, I could have 0, 5, 10, 15, 20, 25, 30 [for each number she says, she hits her hand on a different horizontal line on graph paper on Smartboard], so everything is going to fall in between two lines [puts hands, palms facing each other, against the board]. Are you going to be able to see a lot of changes if it's all between two lines?

Students: No.

Grace: So we want to get the smallest interval we possibly can that we can still fit everything on the graph.

Student: One and a half.

Grace: We could count by 1 and a halves. Kind of hard to count by 1 and a halves though. Do you go around counting by one and a halves?

Student: Sometimes.

Student: Point five.

Grace: I, probably with this instance, because we have so many half degrees [points to table], would actually count by halves. But, I don't want to start at zero, half, one, one and a half, two, two and a half, three, three and a half, four, four and a half, five, five and a half. [For each number she says, she moves her index finger up one line on the y axis on the board]. Because that would take forever. I really want to start at like 20 degrees. Is there any way I can start at 20 degrees?

Student: Yes.

Grace: I can start at 20 degrees, but I need to do something, so that somebody looking at this graph wouldn't go, oh you're counting by intervals of 20 and then all of the sudden start by halves. There's something I can do right here [points to where the x and y axis intersect]. Anybody know what I can do?

Student: It's like [traces index finger in a lightening shape].

Grace: Yeah, it kind of looks like a little heartbeat thing [Grace traces index finger in a lightening shape]. It's a little squiggle, right? So take your pencil and go wheh, wheh, wheh, wheh, like this. [Draws lightning bolt line on the board along Y-axis.] That's like you took a bunch of the graph and went chwuh, and squooshed it. [Grace moves both palms together like she's squishing something]. And so it's sticking out, it's all squooshed right there, like it's a wadded up piece of paper. Then we can start with 20 degrees, 20 and 5 tenths, 21, 21 and 5 tenths, what would come next? [As Grace speaks, she writes the degrees on the corresponding horizontal line on the board, moving up the y-axis.]

After students had made a double line graph, with a blue line representing the rate at which water heated and cooled and a brown line representing the rate at which sand heated and cooled, Grace then instructed her to draw the sketch in Figure 2.15, asking them to use their knowledge about what happens to hot air and cold air to draw arrows indicating which direction they thought the air would move in the daytime and in the nighttime based on what they noticed about the heating and cooling rates of sand on their double line graphs. Afterward, Grace used a similar diagram on the Smartboard as she asked students to place the arrows on the Smartboard indicating the direction of the air above the water and sand at day and at night. The following day, Grace asked her students to write everything they knew about what happened when land and water heated.

Grace's lesson indicates the kinds of semiotic transformations that can happen in earth science prior to writing, along the types of instruction required to support students in making those transformations. Grace's essential question was, *What happens when land and water heat?*, and to individually assess students' understanding of this question, she decided to ask them to write an essay response. Preparation for this essay, however, did not involve a series of drafting and revising in paragraph form. Instead, preparation for this essay required teaching students how to "read" the rate of temperature change in heated land and water. Students transformed the information they obtained from reading the thermometer into a numeric table, which Grace taught them to construct by asking them (a) the important information they should record; (b) how they should record it; and (c) what units of measurement they should use to record this information (e.g., *minutes* and *degrees Celsius*). Moreover, she showed them how to record the information concisely by only writing the units of measurement at the top of the column rather than rewriting it 20 times.

The data underwent another semiotic transformation when students changed it to a graph, a transformation that also entailed explicit instruction. This instruction included asking students

(a) which type of graph they should use; (b) what information should go along the x-axis and y-axis; (c) what type of intervals they should use based on the data they had; (d) how to graph data that did not start at zero; and (e) how to write their numbers “on the lines” of the graphing paper so they could later be used to find points on the coordinate plane.

The data underwent yet another semiotic transformation, this time to a drawing of the beach that later became a diagram when students annotated it with arrows and labeled sea breezes and land breezes. Although Grace did not explicitly discuss how to construct effective diagrams with her students in the same way that she explicitly discussed the construction of effective tables and graphs, she nonetheless provided a model of a scientific image that only included the most salient elements of the natural phenomenon (e.g., sand, water, a moon or sun), while omitting non-salient elements. She explicitly showed students how arrows can be used to indicate direction, in this case of wind.

At this point, the original data (the sand and water) underwent a final semiotic transformation from image to written form. Once again, Grace did not provide explicit instruction in how to write effective paragraphs in this particular instructional episode, but previous lessons included this type of instruction. When her students tried to describe a gluestick as “small,” for example, Grace said that scientists use measuring instruments to quantify their descriptions and led students through a series of questions that led them to conclude they could describe the gluestick as a certain number of centimeters long and a certain number of centimeters in diameter. In this way, she emphasized that in science, language should be as precise and specific as possible. Grace also repeatedly emphasized the importance of logical connections from one idea to the next, asking students to write comments on partners’ explanations if they seemed to be missing important information or logical connections in their essays, at times providing models for students of responses that were complete versus responses that were incomplete.

As these examples suggest, writing instruction in earth science can be an incredibly complex task for many reasons. First, students' writing often synthesizes information from texts that are originally largely non-written (e.g., gestures, diagrams, demonstrations). Second, students' written responses can be the result of a series of preceding semiotic transformations: in this case, a series of transformations from a demonstration with land and water, to a numeric table, to a graph, to an image, and finally to a written product. Along the way, each type of semiotic transformation can require explicit instruction for its successful completion. Finally, sometimes students' final products may themselves be multimodal, requiring students to understand how to effectively integrate modes: how to refer to numeric tables in written text, for example, how to write effective titles for graphs and diagrams, or how to ensure that their images and words do not convey discrepant information.

Possibilities for Representation Instruction

How might teachers approach the complex task of teaching students how to communicate scientifically when the definition of communication is expanded to include multiple modes and a vast array of possible modal combinations? Students can learn to engage in similar types of reasoning that teachers themselves practice as they decide how to communicate scientific concepts. All three teachers, for instance, used globes or other spheres moving in three-dimensional space to teach about the causes of lunar phases and seasons because this type of representation afforded the visualization of moving bodies in space in ways that written words—or even images on a flat surface—could not.

Students, too, can make these kinds of representational decisions rather than completing assignments whose form has already been pre-determined. Repeated conversations can require students to consider the question: “How might we best represent this concept, and why is this form of representation (or these forms of representation) an effective choice?” Some students may decide that an effective way to represent global winds, for example, would be to verbally narrate gestures over a globe, while others may opt for a diagram that uses arrows to show the direction of winds at different lines of latitude on a circle representing the earth. As teachers expand the representational possibilities for assessment, students can practice metadiscursive thinking about *how* and *why* they might represent concepts in earth science in particular ways as they discuss the affordances and constraints of various representations and as they justify their representational decisions.

Representation in earth science does not just encompass representing a concept after people have arrived at developed understandings, however. Although earth scientists do present polished reports of their research in a variety of ways, they also use multiple forms of representation as a means of arriving at those understandings. Students can also be encouraged to think about how they might use different types of texts—writing, drawings, numbers, graphs, and so forth—as a means of thinking through problems. Charles Darwin, for example, used drawings to develop theories about evolution, and Alfred Wegener sketched a series of maps to reason about seafloor spreading. Using the same mode, Tracy’s students drew the types of clouds that appeared in the sky every morning for a week, noted the weather that day, and used their drawings to infer possible meanings of different shapes and colors of clouds.

In contrast, as Grace’s students learned about sea and land breezes, they did not initially record the data through images; instead, they recorded data through numbers, which they later transformed into a line graph to help them actually “see” changes in temperature when the brown line representing the rate of the sand’s temperature change was much steeper than the blue line representing the rate of the water’s temperature change. In this way, the line graph served as a representational tool designed to help students think in a different way about the numeric table and about temperature changes in heated land and water. Students can discuss how these types of semiotic transformations (from numbers to graphs, from graphs to diagrams) can help them to reason about scientific concepts in distinctive ways as they ask themselves questions such as, “How might I represent this idea in another way? How would representing this idea in a particular way help me to solve this problem?”

Critical Literacy Instruction in Earth Science

Earth science, like any discipline, is shaped in part by social and political contexts. Historically and currently, institutions of power—from churches to federal governments to big businesses—have legitimized and promulgated particular scientific theories by the work they fund and endorse in official publications. At the same time, these institutions of power have castigated or ignored other forms of scientific research, relegating them to the margins. In writing of the fields of power in which scientific research is conducted, Bazerman (1998) drew from Latour’s (1987) work to argue that scientists are “powerful rhetorical actors enlisting others in networks, to serve as resources in trials of strength with the critiques, claims, and projects of competing techno-scientists” (p. 16).

As rhetorical actors who seek funding and recognition, one technique that scientists often use across texts is high *modality,* defined as the degree to which the message of text is assumed to *real, true,* or *taken for granted* (Halliday, 1978). Linguistic markers such as *in my opinion* and *I feel* indicate that a text’s content is subjective, whereas sentences such as the following (which was read by Grace's students) are designed to make its content seem undeniable: "DHMO is a causative agent in most instances of soil erosion" (http://www.dhmo.org/environment.html). In this sentence, the word *is* claims *DHMO* exists objectively as a *causative agent of erosion.* The nouns *causative agent* and *erosion* "arrest" the verbs *erode* and *causes* as concrete things whose existence is also rendered undeniable (Halliday & Martin, 1993). This sentence also addresses "what nature does, rather than the actions of the investigators and their interpretations of what nature does" (Russell, 2010, p.19), an approach that conceals that science is a human endeavor fraught with contradictions and disagreement as people generate evidence-based (yet debatable) suppositions (Knain, 2001).

High modality is not just created through words, however. Indeed, as the teachers from this chapter have demonstrated, much of earth science is communicated through other types of texts as well. The website from which that sentence was taken, for example, contained a disturbing photograph of "DHMO-contaminated sewage," adding to the veracity of the claim that dihyrodgen monoxide is harmful. In addition to the use of scientific language and photographs, the website further claimed high modality by being produced as part of the Dihydrogen Monoxide Research Division, a subset of the United States Environmental Assessment Center.

Grace's students read the website, which used scientific language to argue that DHMO should be banned because it has "led to the loss of life and destruction of property," among other reasons. Convinced by the dangers of this substance, her students all signed a petition to their local congressperson to ban it, at which point Grace informed them they just tried to ban water. She used this example to discuss how the use of scientific language and other convincing representations (in this case, photographs)—and even the endorsement of alleged "research divisions"—do not necessarily make an argument valid, and students can approach all seemingly credible scientific texts with a skeptical eye.

Another example of a famous image from earth science, Copernicus's diagram of the sun-centered universe, will illustrate how discussions of modality can support students in developing critical literacy. Kress and van Leeuwen (2006) have argued that, for scientific images, "modality is higher the more an image reduces the individual to the general, and the concrete to its essential qualities" (p. 171). They argued that high modality can be established by eliminating details such as naturalistic color and backgrounds, and by adding labels, lines, and numbers. Copernicus used these communicative techniques to argue for a sun-centered universe. However, other people used this same technique to make persuasive counter-claims; in fact, geocentric diagrams were still published for centuries after Copernicus's (1542) *On the Revolution of the Heavenly Spheres.* In 1632, almost a century later, Galileo was sentenced to house arrest in part for his support of Copernicus's theory.

One could imagine a lesson in which teachers showed these competing diagrams (see Figure 2.16), discussing why one was promoted and the other denounced as scientists continued centuries of debate over the nature of the universe. Students could also discuss contemporary images of the solar system and universe, emphasizing that as late as 2006, scientific communities changed their mind about Pluto's classification as a planet. Students can note that each image of the universe or solar system, no matter how absolute it seems, is open to modification as social contexts change and as new technologies make new evidence available. By showing how current scientific images—whether of the universe or another phenomenon—have competed with other images and have changed over time, students can learn that even "factual" texts produced by reputable scientists are subject to change, and that science is a living field rather than a decided one.

Limitations of Representation

Along with refusing to be convinced by a scientific text just because of its high modality, students of earth science can learn to question representations based on what each mode itself can and cannot convey in relation to its referent. In this way, critical literacy instruction in earth science can entail attending to how a given mode conceals or distorts aspects of the natural world. For instance, in one lesson Grace hit her forearms together at three different speeds to indicate how sound waves move through liquid, solids, and gases. Although Grace's arms showed that sound moved faster or slower through different mediums, the speed of her arms could not approximate the speed of sound moving through air. Moreover, the shape of the movement of her arms did not approximate the movement of sound waves.

Much has been written about scientific "misrepresentation," especially as it appears in textbooks, and its likely negative impact on student learning. However, as this example suggests, gestures and other non-print texts also have the potential to be misleading. In Nancy Rae's classroom, for instance, clay models represented rocks moving through the rock cycle, simulating some aspects of rocks' visual appearance but misrepresenting the *time*, *heat*, and *pressure* required for rocks to undergo such changes. Likewise, graham crackers on a plate of frosting represented tectonic plates, simulating the direction of plate movement but misrepresenting the *relative density*, *composition*, and other characteristics of tectonic plates.

Rather than viewing these texts as *misrepresentations*, texts in earth science classrooms can be viewed as *partial representations* (Freebody, Luke, & Gilbert, 1991) whose affordances, tied to their physical properties, enable them to convey only certain aspects of a given phenomenon while excluding others. A critical approach to reading representations in earth science, therefore, can entail reflections in which students comment on how a text—whether it is a gesture, a model, or something else—was *unlike* what it represented as well as *like* it. This critical approach can entail showing students multiple representations of the same phenomenon (e.g., gestures of sound waves and a textbook diagram of sound waves) and asking them to identify the affordances and limitations of each representation—in effect, asking them to identify what each text can convey and what it cannot.

Reading and Acting

As many of the examples described throughout this chapter suggest, reading in earth science is not a physically passive act; instead students often manipulate focal texts in different ways. Likewise, if the world is a primary text for earth scientists, they, too, perform physical actions in relation to this text as they take samples (e.g., of glacial ice or of soil), manipulate objects to make certain types of observations (e.g., scratch an index mineral across another mineral to ascertain its hardness), and plan experiments designed to measure the results of interactions among elements in the world.

Accordingly, part of critical literacy in earth science requires students to think critically about how scientists' actions influence the claims they make: how the timing and the placement of their samples influenced the results they obtained; how their handling of the technological instruments influenced their readings; how contaminants or other variables might have affected the results of their experiments, and more. In other words, a central question to critical literacy in earth science is the word *how?: How* did the scientist conclude that global warming is occurring?, *How* did the paleontologist name the age of this fossil?, *How* does the meteorologist know that the hurricane will not reach our city?, and *How* do geologists know that the San

Andreas fault in California occurs at a transform boundary? Rather than simply accepting claims, critical literacy in science entails asking questions in regards to *how* that claim was made as people physically collected and analyzed data.

Different activities can teach students to take this critical approach as they question the processes—including the actions—that scientists use to make claims. Tracy's students, for example, read thermometers as part of a lab, during which time two students simultaneously read the same thermometer but recorded different temperatures. Students could have used this and similar opportunities to discuss how human error or imprecise measuring instruments can lead students (and scientists) to make incorrect inferences. Class experiments that do not turn out as planned can lead to similar discussions, emphasizing the importance of repeating tests or observations as a means of verification.

As another example of critical literacy instruction that encourages students to question how scientific claims are physically enacted and tested, students could also examine ads for relevant products, such as websites advertising water purification tablets or soil fertilizers. Students can design experiments that the company would have needed to perform in order to substantiate their claims, including claims that a specific water purification tablet kills 99 percent of bacteria or that a particular brand of soil fertilizer produces vegetables that are 30 percent larger than average. By participating in activities such as these, students would have to critically think about *how* scientific claims are (or are not) grounded in people's tests and actions.

Science as Social Action

As the American Association for the Advancement of Science (2009) has suggested, "science cannot be used by itself to establish that an action is moral or immoral" (Benchmark 1A/M4c), and by this standard, devastating hurricanes and years of low rainfall that lead to severe droughts are not *immoral,* either. At the same time, acts of nature—from rainfall to hurricanes—do not occur in a neutral world, and these acts can be shaped by human activities embedded in fields of power. Some communities, for example, are better able to prevent erosion due to well-funded infrastructures that manage agricultural and urban projects. Hurricane Katrina itself may not have been immoral, but there is debate about the morality of the ways in which victims in New Orleans received assistance according to their race and socioeconomic status. It may be a "fact of nature" that less than one percent of the world's water is drinkable, but this seemingly neutral "fact" is accompanied by an unequal distribution and management of water, leading to avoidable drought in places without strong water management systems and decades of tension between competing groups that claim water sources.

In sum, "natural activity" is intertwined with human activity on a global and local scale, and although subjects such as *water* or *erosion* may be neither moral nor immoral, they have a tremendous impact on human life in ways that privilege some people over others. Part of critical literacy in earth science, then, can entail a critical look at the distribution of resources as students take action in their respective communities. From examining plans to place landfills in particular locations, to noting areas where erosion is more pronounced versus where it is more actively managed, to discussing how different buildings have established precautions against natural disasters while others are relatively unprotected, to testing local water quality, to examining the city's statistics on recycling and waste, students can use available information to advocate for a more responsible and equitable community and world.

Chapter Summary

In all, earth science was a discipline instantiated through diverse modes whose affordances enabled teachers and students to communicate their understandings of various aspects of phenomena on Earth and in the universe, including their movement, shape, spatial position, physical composition, and scope. Because students regularly made sense of multiple modes on a daily basis, a rigorous model of comprehension instruction would account for these modes by explicitly teaching students how to regulate their thinking processes as they made sense of gestures, images, demonstrations, models, and so forth. Though this type of comprehension instruction might parallel traditional comprehension instruction in the sense that students could apply similar types of strategies to gestures as they would to written texts (e.g., asking questions), this type of comprehension instruction is different in several ways as well. For example, this type of instruction would help students' understand how their physical interactions—such as the angle at which they view it or the way in which they manipulate it—might affect the text's meaning. As part of critical literacy instruction, students can consider how the affordances and limitations of individual modes might conceal, distort, or enable the representation of certain properties of a referent.

Along with critically reading multimodal texts, students can also learn how to generate multimodal texts for a variety of purposes, such as recording data, reasoning through a problem with others, summarizing what they have learned about something, or justifying an inference. Students can be brought into conversations regarding how they might represent something and why they would represent it that way, including an acknowledgement of the semiotic transformations required prior to a creating a final product.

Table 1

Texts Used in Earth Science in 175 Instructional Episodes

Non-Written Texts (n=473)	Written Words (n=275)
Gesture: 102	Instructions: 61
Diagram: 58	Textbook section: 50
Photographs: 41	Questions: 39
Drawing: 33	Multiple-choice questions: 38
Moving image: 25	Informational paragraph: 21
Demonstration: 24	List: 18
Lab: 24	Definition: 15
Model: 23	Article: 14
Graphic organizer: 22	Narrative: 11
Embodied representation: 21	Criteria: 6
Map: 17	Informational Book: 2
Table: 15	Poem: 1
Object: 11	
Natural world: 10	
Numbers and symbols: 10	
Measuring instrument: 8	
Graph: 6	
Manipulative: 4	
Symbols on existing text: 2	
Coordinate plane: 1	
Number line: 1	

Causes of Physical Phenomena
What causes severe weather?
Where does wind come from?
Where does the rain come from?
Why do we have seasons?
How is rock weathered?
How is convection related to weather?
What happens when the plates wiggle?
What processes change rock?
What causes waves, currents, and tides?
What happens when the sun heats land and water?
Why do we have phases of the moon? (x2)
How does the tilt of the earth's axis affect climate?
What causes hurricanes, tornadoes, and thunderstorms?
What events take place during the rock cycle?
What kinds of processes occur in the water cycle?
How do weathering and erosion affect the earth's surface?
How does the relative position of the earth, moon, and sun affect us?
How does the distribution of land and oceans affect weather and climate? (x2)
What geological events are caused by the movement of lithospheric plates? (x2)

Scientific Methods
How do meteorologists study the weather?
How do meteorologists predict the weather?
How do I make a valid test? (x5)
How do we know the earth's surface is changing?
What makes models such a great science tool?
Can I keep clear and accurate records in science?
What are the steps of the scientific method?
What are process skills I need?
What is the scientific method?
How do I measure in science?
What do I know about SI (international system of units) and earth science?

Describing Physical Phenomena
What is dirt?
What is the earth made of?
What are the layers of the earth?
What is a non-renewable resource?
What are renewable and nonrenewable resources? (x4)
What are the topographical features of the ocean?
What are the properties of minerals? (x2)
What do I know about rocks and minerals?
What is my intergalactic address?
What are the characteristics of the inner planets?
How do the planets compare to Earth? (x2)
What are the differences between types of plate boundaries?
How can I deepen my understanding of the earth's structure?
How are tornadoes and hurricanes similar and different? (x2)
How would you describe the composition, location, and subsurface topography of the world's oceans? (x2)

Figure 2.1. Essential questions in earth science.

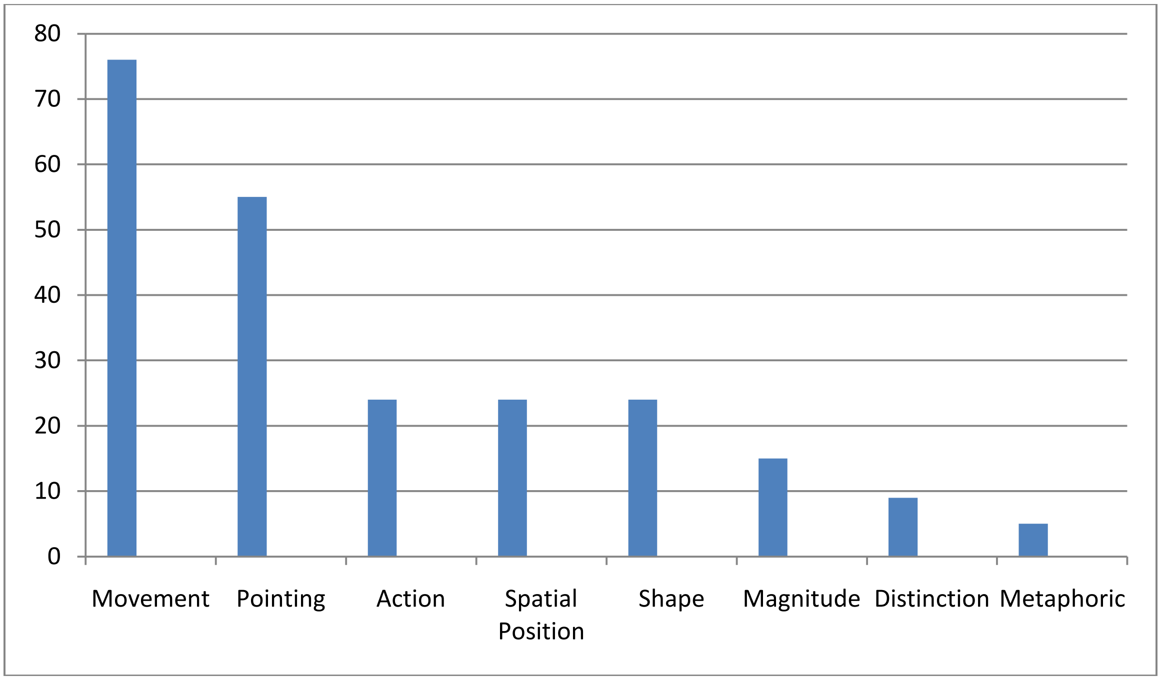

Figure 2.2. Types of gestures used in earth science.

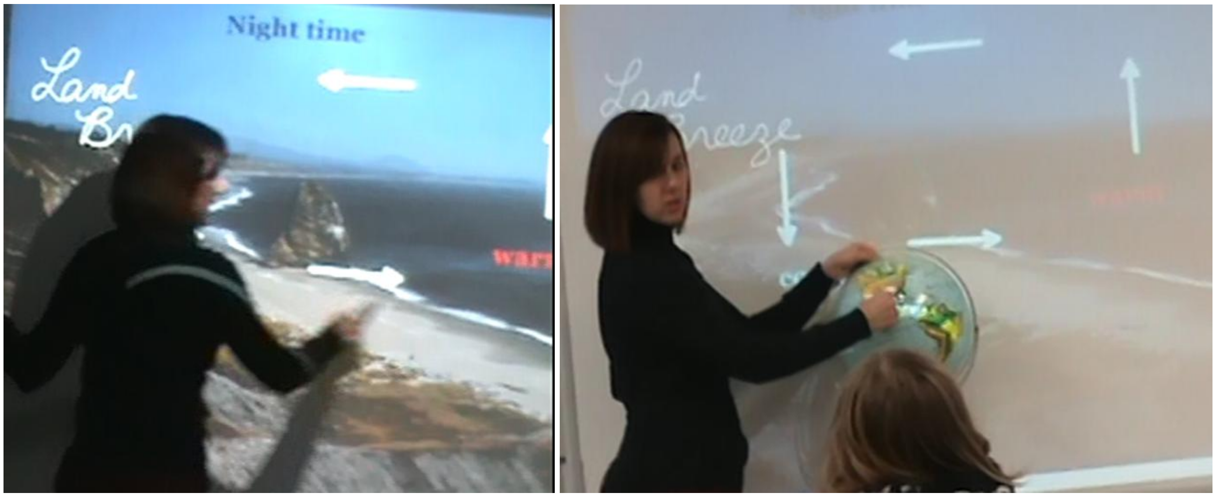

*Figure 2.3***.** Gestures and a globe laminate the diagram.

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Figure 2.4. Gestures and lines depict the rock’s shape prior to centuries of erosion.

Figure 2.5. Sliding hands represent transform boundaries.

Figure 2.6. Grace’s hands depict ice wedging.

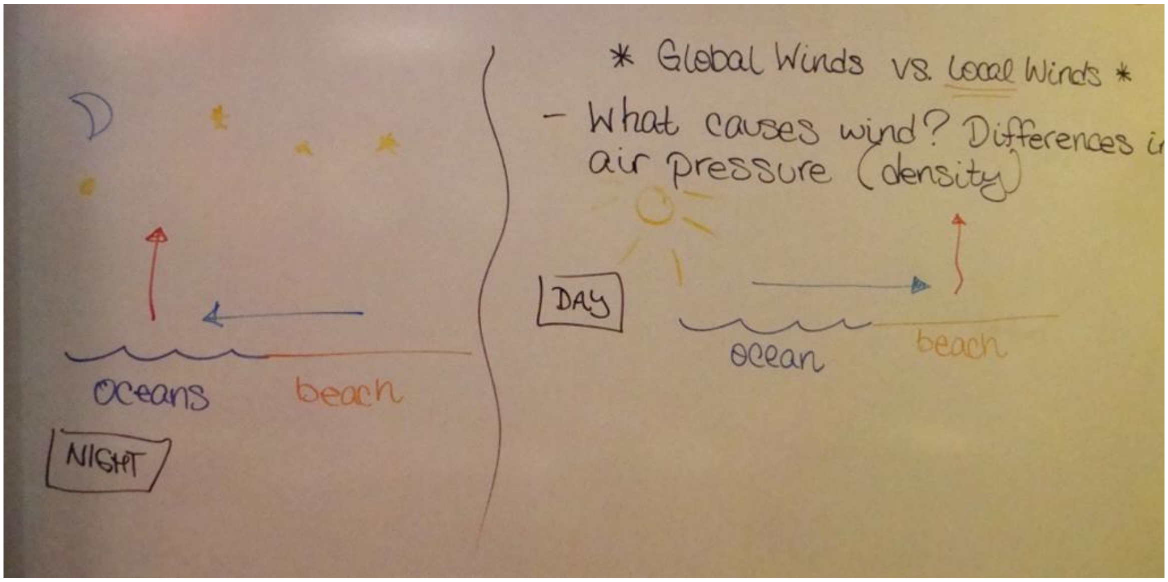


Figure 2.7. Two diagrams explain the causes of sea and land breezes.

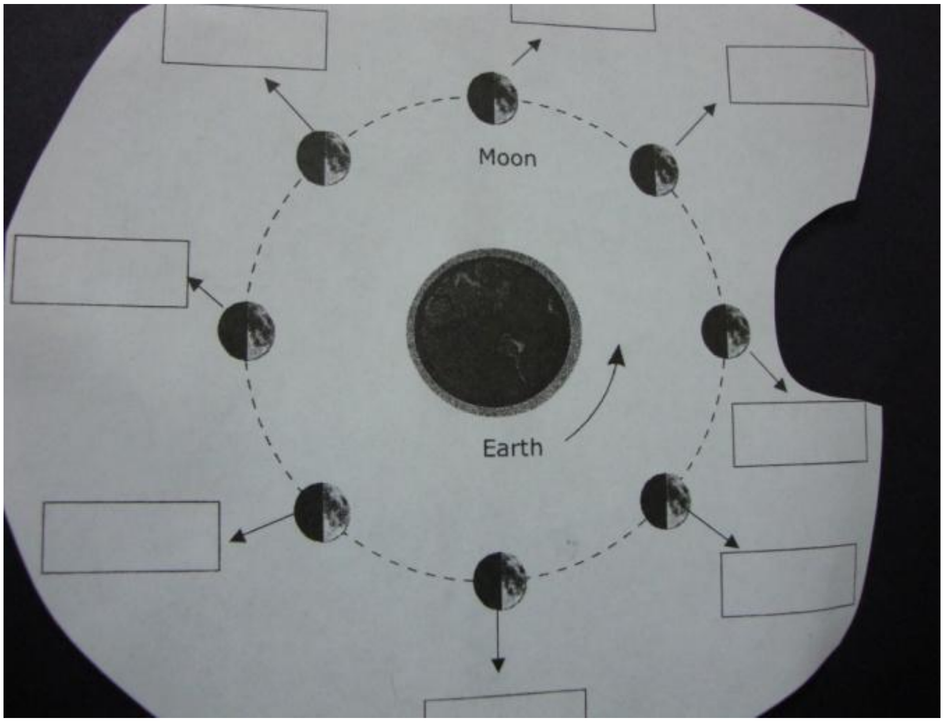


Figure 2.8. Diagram explaining the causes of lunar phases.

Figure 2.9. Puzzle pieces used to represent continental drift.

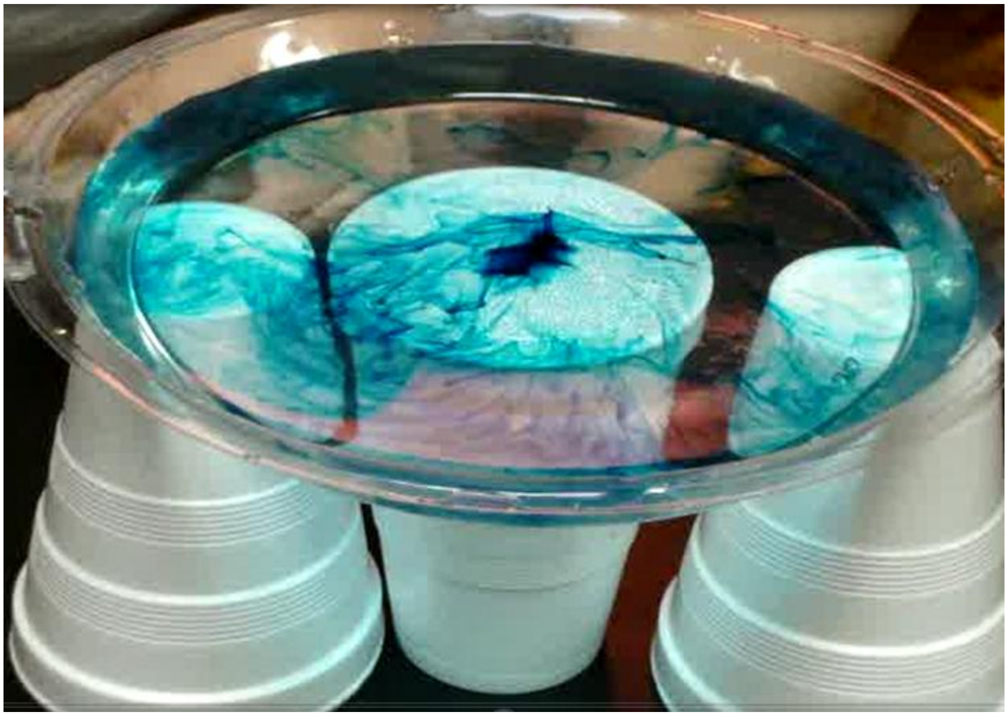


Figure 2.10. Lab used to show the causes of convection currents.

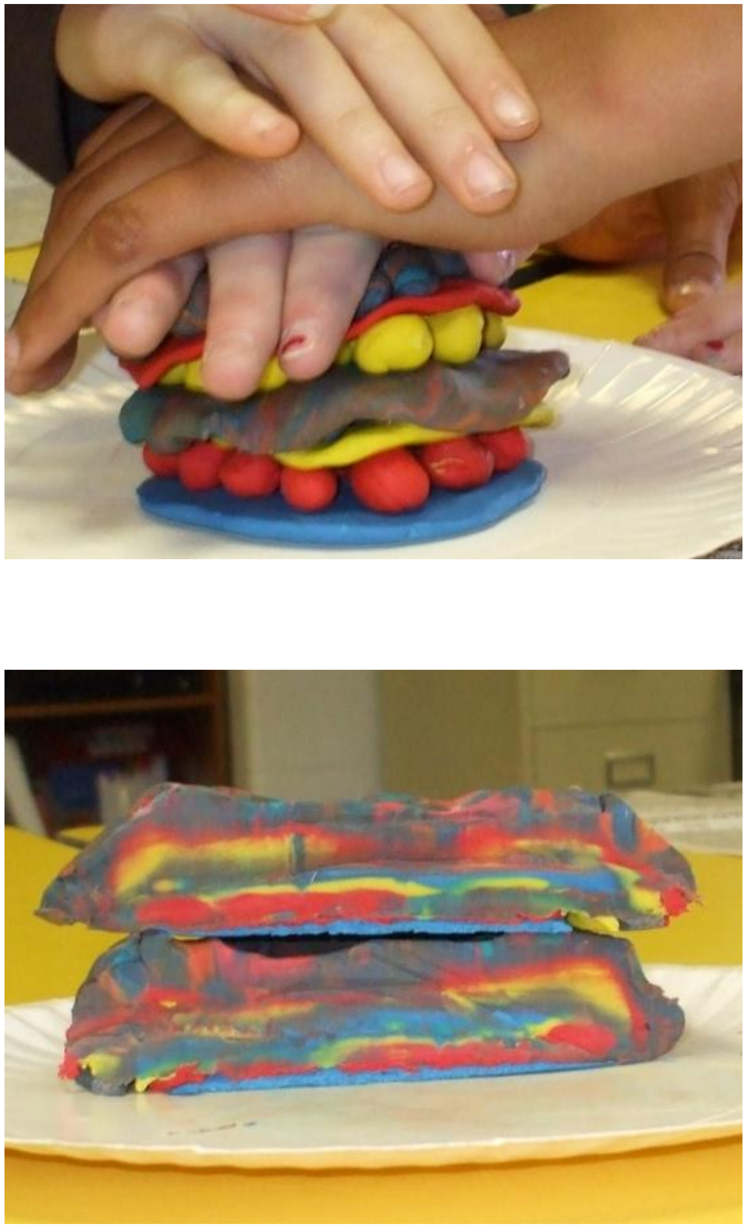


Figure 2.11. A sedimentary rock transforms into a metamorphic rock.

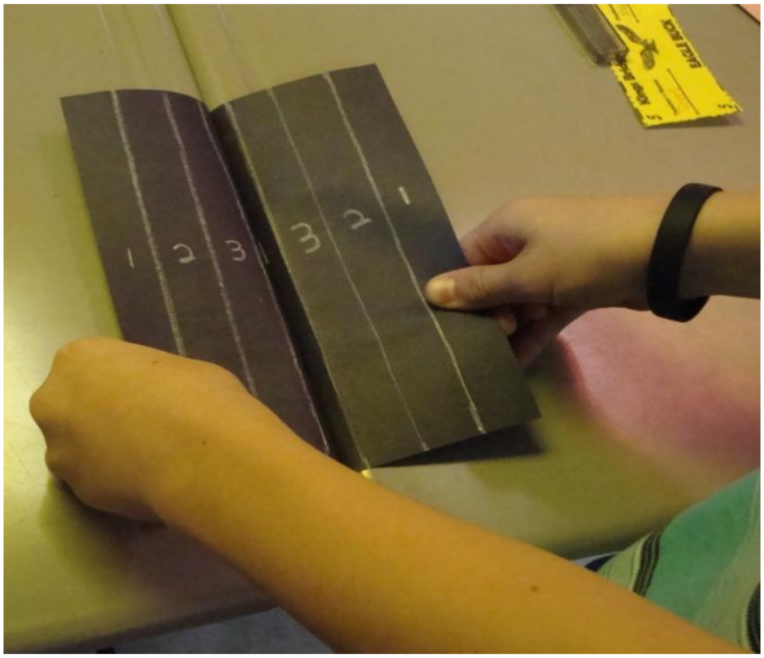


Figure 2.12. Paper used to represent magma pushing out of the mid-ocean ridge.

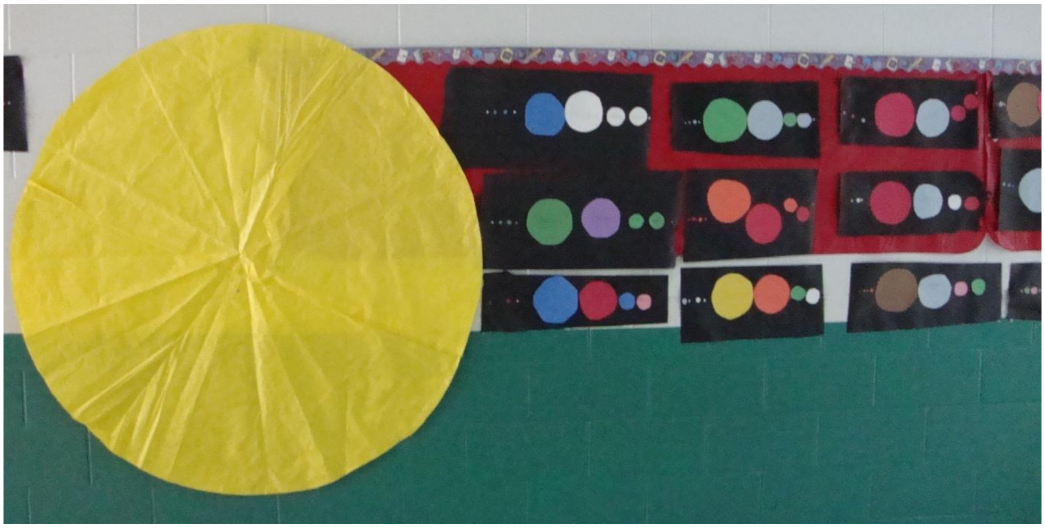


Figure 2.13. Scaled model of the size of the sun compared to the size of other planets.

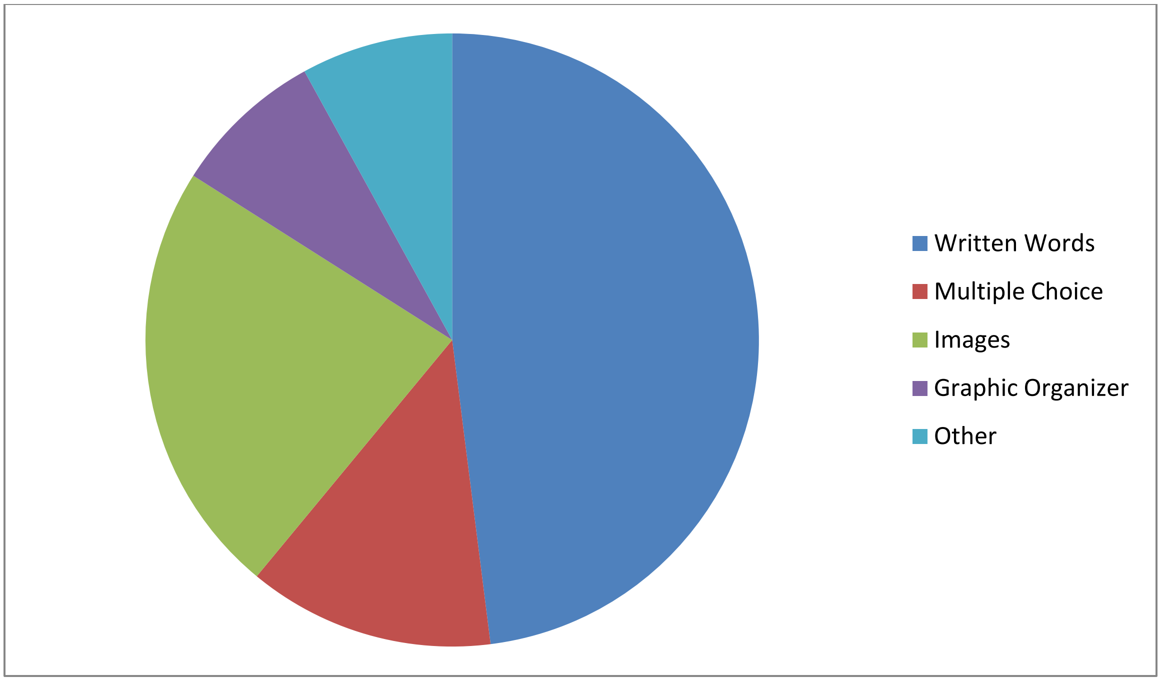


Figure 2.14. Modes used for assessment in earth science.

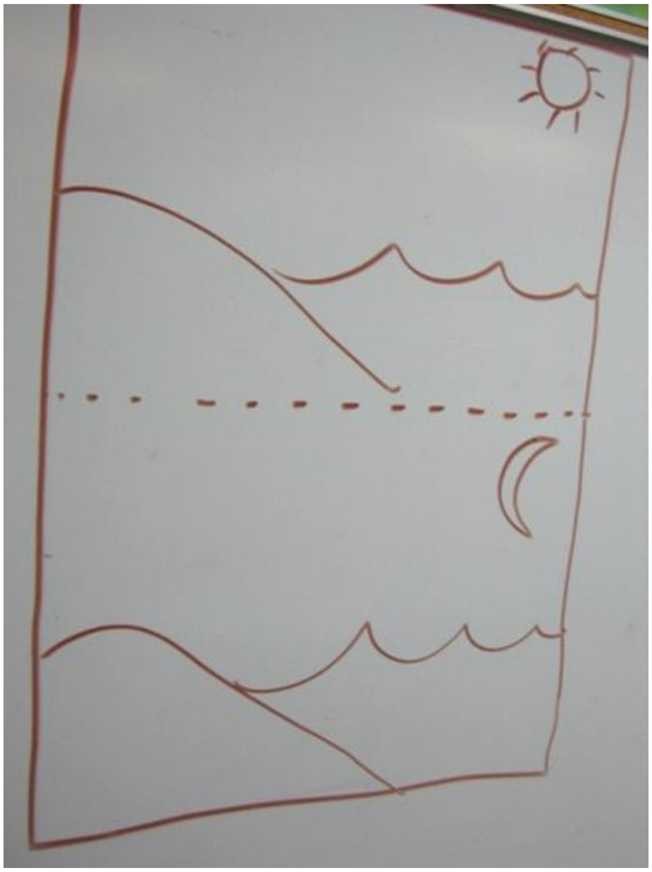
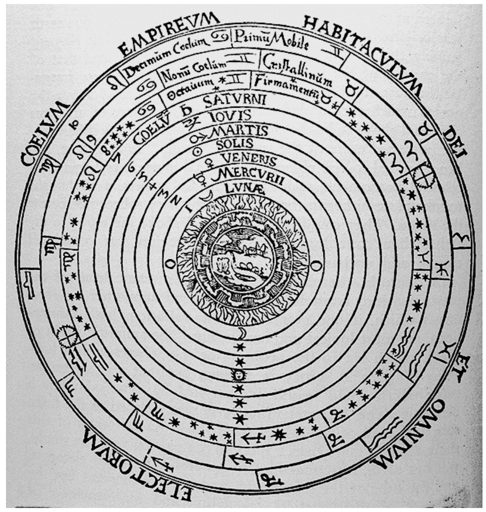


Figure 2.15. Drawing template used to teach the causes of sea and land breezes.



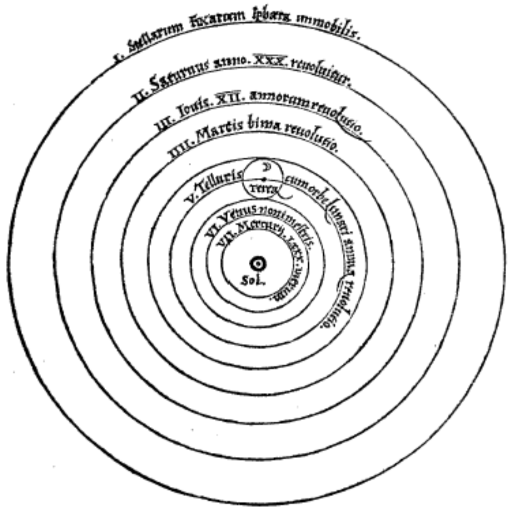


Figure 2.16. (Top): Geocentric and heliocentric diagrams of the universe. (Top) from Peter Apian’s *Cosmographia*, 1524; (Bottom) from Copernicus’s *De Revolutionibus Orbuium Coelestium*, 1543.

CHAPTER 3

READING AND REPRESENTING IN ENGLISH

On a constant basis, we as human beings communicate with ourselves and the world around us. We may speak with our family members in order to accomplish a mutual task, laugh as we watch a television show, post photographs on social networking sites, and participate in countless other acts of communication as listeners, readers, viewers, and generators of texts. The discipline of English has been devoted, at least in part, to the study and practice of these acts of communication. How texts are structured at a micro- or macro-level; how texts are used for different purposes in different contexts; and how texts are interpreted through a variety of theoretical approaches can all fall under the designated province of English.

To what end do people study and practice various mediums of communication? According to the National Council of Teachers of English and the International Reading Association (1996), it is to ensure that all students have opportunities to “develop the language skills they need to pursue life’s goals, including personal enrichment and participation as informed members of our society” (p. 1). What it means to pursue life’s goals, of course, will take different forms as different people pursue goals related to the social values in the cultural settings that surround them (Cole, 1996). These life goals are tied to desired, projected, and perceived identities as students imagine who they want to be, what they want to accomplish, what they want to have, and with whom they want to be affiliated. Because students’ desired social futures are diverse, the language skills required to achieve those futures—from hip hop artist to birdwatcher—are also diverse (Gee, 2008).

People who speak Appalachian English, for example, may proudly do so as a way to assert self-proclaimed identities as "mountain folk" (North Carolina Language and Life Project, 2008), while English language learners may likewise hold to home languages as a means of connecting to their families, countries of birth, and personal histories (Peirce, 1995). As part of its instruction on communication, therefore, English as a discipline can include explicit discussions of language and identity (Fecho, 2004) as diverse students reflect on how and why they might use different forms of language while communicating with different audiences for different purposes as they engage in "the most fundamental aim of language—to promote interaction among people" (Dixon, 1967, p. 6).

If language skills are diverse in nature and inextricable from one's unique social context and life goals, what texts might teachers use to further students' awareness of and proficiency with language in a pluralistic society? Debates over what constitutes a *text* in English have long proliferated among teachers and professors in the field (Elbow, 1990; Scholes, 1998). National organizations and standards have not settled this debate, claiming that English as a discipline should address "a wide range of print and non-print texts" (NCTE/IRA, 1996) or that it should address a variety of "complex literary and informational texts" (Common Core Standards, 2010).

To be sure, this seemingly wide latitude in text selection does not always translate into classroom practice: District mandates, department expectations, and long-held traditions of teaching canonical novels to transmit an often Eurocentric "cultural heritage" curtails the types of texts that are available to many English teachers (Applebee, 1993). Nonetheless, standards-based definitions of 'text' in English can theoretically (or actually) provide teachers with the option to select texts primarily because they would be engaging or meaningful to their particular students: their favorite songs, magazine articles about local sports stars, bilingual books whose characters grew up in a neighboring community, and more.

According to national standards, English teachers should also select texts because they encompass a broad range or variety of features, genres, and time periods. The purpose of this criterion for text selection is to enable discussions of how various purposes for communication are reflected in each text's structure and features. Students both read a range of texts, noting how their features achieve particular ends, and they write texts in turn that include these features. As a mainstay of composition instruction, students learn to explicitly reflect on the processes by which they write (Emig, 1971). These processes may include strategies for "planning, revising, editing, and rewriting" (Common Core Standards, 2010, W.6.5), such as brainstorming ideas through discussions and drawings; organizing ideas through outlines, graphic organizers, lists, and storyboards; revising ideas through annotating and rewriting; and sharing their ideas with others, all of which students do in recursive ways that vary by individual.

Although teachers of English can require their students to read and compose a range of texts whose subjects encompass topics from other disciplines, English is nonetheless characterized by a distinctive body of texts in its own right. Specifically, this discipline emphasizes literary works, including poetry, drama, short stories, novels, and other genres whose subjects might exist solely in the author's imagination. As students read and view these narratives, they often follow a (more or less) sympathetic character through the "ebb and flow of everyday human activity" (Dixon, 1967, p. 57; cf. Bruner, 2004), evaluating and connecting to her or his choices and actions.

In English, for example, students might discuss how the untimely death of his parents affected Maniac Magee (Spinelli, 1990); why Edna swam out into the ocean with no chance of return (Chopin, 1899); why Sethe killed Beloved (Morrison, 1987); why Kyle responded as he did upon reading “queer” on his locker (Sanchez, 2001); or why Ellison’s (1952) protagonist identified himself as invisible. Through discussions around these types of texts, English as a discipline invites students to speculate on characters’ psychological states and motivations; to empathize with their dilemmas; to evaluate the morality of their actions; and to reflect on implications for their own personal lives (Langer, 2010). In other words, “literature provides a terrain for interrogating the meanings of human experiences” (Goldman, 2010, p. 29) and lends itself to discussions about “the art of effective living” (Parker, 1937, p. 9). In this way, English as a discipline holds a special potential, not only to support life goals, but to host transformative conversations that interrogate those goals as students reconsider longstanding cultural values, assumptions, expectations, and trajectories (Fecho, Collier, Friese, & Wilson, 2010).

Reading practices in English are distinctive in another way as well: Enjoyment is a goal in and of itself in this discipline. Whether it’s laughing at one character’s antics, crying at another character’s death, or staying up late to finish a book that cannot be put down—the discipline of English provides a designated space for actively fostering an affinity with and for texts (Grossman, 2008), goals that are accomplished in part through allowing individual students to select a text based on no criteria other than that they like it. Reading for entertainment or pleasure is not the only purpose for reading in English, however. As part of the discipline’s focus on language skills, the act of reading itself is directly examined as different approaches toward reading are explored and legitimized.

For instance, students read to obtain information as they explicitly practice a variety of comprehension strategies designed to help them approach texts, such as *summarizing*, *monitoring comprehension*, and *inferring* (Flood, Lapp, & Fisher, 2003). Students can adopt a critical stance toward texts as they question how authors employ certain types of persuasive rhetoric and as they note how texts portray and position certain groups (Alvermann & Hagood, 2000). Students may read texts from a feminist perspective as they critique authors' depictions of women, from a new critical perspective as they explain "*how* a poem means" through its use of imagery and other literary devices (Brooks & Warren, 1938), or from a variety of other theoretical lenses and stances (Appleman, 2009). Though the act of reading may be approached in any particular way in a given lesson, English as a whole focuses on different *purposes* for reading, *ways* of reading, and *views* of reading, just as it focuses on different kinds of *texts* and purposes for *writing*. This focus on receptive and expressive language skills is part of the discipline's overall attentiveness to the medium of language itself.

Perhaps the oldest tradition for studying the form of the English language, at least in established educational institutions, has been grammar instruction (Applebee, 1974). In his history of the development of college English courses, Graff (1987) described college students from the turn of the 20th century who read works of "great literature," but "from first to last, they were simply conglomerations of ablative absolutes, vocatives, gerunds…thus we were taught the classics" (p. 29). Far from being a tradition that has fallen out of use, similar types of grammar instruction remains a fixture in many language arts classrooms (Hillocks & Smith, 2003), despite a sizeable body of research suggesting its limited potential to improve writing (Andrews et al., 2006; Braddock, Lloyd-Jones, & Schoer, 1963). Some individuals, (Delpit, 1995; Schweiger, 2010), however, believe that explicit instruction on grammatical structures provides people from various linguistic backgrounds with access to the structures of English; and explicit knowledge of the structure of individual sentences remains a component of state and national standards (e.g., Common Core Standards, 2010).

In sum, English as a discipline has a long history of focusing on the medium through which human beings communicate with each other and with themselves: language. Although the National Council of Teachers of English has expanded this definition of language to include “visual language” such as images, historically the focus of study has been in large part on written and spoken words, a tradition that is still present in contemporary classrooms. As students read for entertainment, write for personal expression, or participate in a host of other communicative tasks—English as a discipline can enable students to reflect on the power and forms of texts as they communicate for different purposes in different settings.

Teachers’ Conceptions of English

Nancy Rae, Alice, Francine, and Annette each held conceptions of English that resonated in many ways with the national standards for their discipline. When asked what she wanted her students to come away with from her class Nancy Rae responded,

> It would be great if they could come away from it with a love of reading…it would be great for them to realize the importance of language, and the importance of reading, the importance of writing. Like I tell them a lot I don’t speak grammatically correct all the time, I know I don’t. But when it counts, I know the difference of when to pay attention and be very careful….You’re going to speak very differently to your best friend or your grandma than you would on an interview with somebody or on camera. So knowing to, knowing what’s correct when it counts, I think you just know that language is important.

As this quote suggests, in alignment with the goals outlined by the National Council of Teachers of English (1996), Nancy Rae believed that a basic goal of English was for her students to use forms of language that varied in accordance with their audience and context of communication.

She also underscored her desire to foster an appreciation for the power of language and promote a love of reading.

Annette shared a similar goal when asked what she wanted her students to come away with:

> I want them to have a love of reading. That helps with everything. The children here in this [rural] county have such a—their base knowledge is very limited. I want them to let reading be a key to building that base knowledge so that they can be successful in college. Most of them, if you ask in sixth grade, "What do you want to be? Are you planning to go to college?" their answer is yes, they're planning to go to college. I want them to be able to fulfill that dream. That would be my hope, that they would be able to do what they want to do as a sixth grader.

In one sense, Annette shared the same vision as the one outlined by NCTE: that her students use her discipline to pursue their life goals, or—in her words—"be able to do what they want to" and "fulfill that dream." Like Nancy Rae, her first stated goal for her students was to foster a love of reading, which in Annette's eyes would "help with everything" as they learned of knowledge and ideas beyond their rural area.

Francine, too, believed English served as a platform to further students' individual ambitions, regardless of what they were, through helping them become more powerful readers and writers. When asked what her goals for her students were, she responded:

> As they go to college or if they don't, they need to be able to communicate well and to express their ideas well and to be able to understand what's going on in the world around them through reading. Whether it's on the internet or, you know, text on a newspaper

> page, they need to be able to do those things no matter where they are or what job they have or what path they choose in life.

Alice likewise thought English “helps with everything.” When asked, “What is English/language arts?,” she responded:

> Well I think language arts is like everything. I have a philosophy that there’s nothing that you can do in life that doesn’t relate to language arts in some way. And a lot of that is because it’s reading and writing…but it’s more than that. It’s like learning about yourself, learning about what you think. It’s like learning to express yourself and learning your style and learning who you are. Language arts is more like the touchy-feely stuff. It’s where you learn about your kids because a lot of times, they’ll tell you more…than they would in any other class. And, you know, language arts is—one of my favorite things about language arts is that there’s not ever really a wrong answer. Like when it comes to writing something, there’s not really a wrong answer. It’s not like two plus two is always four. There are multiple ways of looking at things just like there are tons of different ways of looking at literature. That’s probably what I like most about it because it’s not always the same thing.

Like others who have asserted that English seems “more personal” than other disciplines (Elbow, 1990; Siskin, 1994), Alice maintained that the goal of English was not simply to learn about communication but also to learn about oneself. Although she also taught social studies, she maintained that English is the primary discipline “where you learn about your kids” due to the nature of writing assignments, the subjects for discussion, and the allowance for individuals to develop interpretations that diverged from others’.

The teachers' daily essential questions also provided insight into how they enacted their perceptions of English (see Figure 3.1). Most questions were designed to help students read and write a variety of texts about unspecified subjects, drawing students' attention not to the text's content but to its form. This attention to form over content was indicated by the essential questions related to grammar instruction and to the characteristics of particular genres. In other words, the essential questions indicated that knowing the *content* of a sentence or story was not the end goal; rather, the point was to understand how these texts were *structured*. Other essential questions, too, relatively ignored the content of texts by emphasizing instead the processes required to read or to write texts whose subjects remained unspecified. Only 16% of essential questions named a specific text and engaged students in the content of that text, oftentimes by asking students to reflect on themes such as pride, fear, security, or other psychological and emotional themes.

Texts in English

To reach these goals of understanding texts' structure and form, teachers relied heavily on the mode of written words, which comprised 72% of total representations (see Table 2). Even when other modes were used—most commonly *symbols on existing texts*, *gestures*, and a variety of *images*—these modes tended to be ancillary to written words, a point that will be elaborated later. In one sense, then, an analysis of various' modes respective affordances in instantiating the discipline of English seems somewhat impractical because the vast majority of focal texts were written. This chapter describes those focal texts, including the affordances of non-written texts when they were used in comparatively limited instances. This chapter then speculates on why English as a discipline was primarily linguistic as a means toward reaching disciplinary goals. Finally, the chapter moves toward a consideration of how multiple modes might be integrated on a more regular basis in ways that are still authentic to the goals of the discipline and in ways that resonate with national standards.

Sentences and Symbols on Existing Text

To understand why annotated sentences were the most common text across the four teachers' classrooms (see Figure 3.2 for an example), it is perhaps first important to understand the context in which the teachers worked. The four sixth-grade teachers were each held accountable to state standards in several ways, including end-of-year multiple choice tests and a middle grades writing assessment. Nancy Rae and Alice were required to post the standard that they were addressing for each day in their classrooms, while Francine submitted weekly lesson plans to her principal that named the standards she was teaching for the week.

These state standards delineated that sixth graders should know specific parts of speech. For example, they specified that a student "identifies and uses nouns—abstract, common, collective, plural, and possessive; identifies and uses pronouns—personal, possessive, interrogative, demonstrative, and indefinite," and so forth (Georgia Performance Standards, 2006, ELA6C1.i and ii). As this excerpt suggests, the standards not only required students to use a variety of nouns and pronouns, presumably in their writing, but also to identify examples of words such as indefinite pronouns as they appeared in sentences on the end-of-year tests. Although teachers were not supposed to see the end-of-year tests, Francine, who had proctored it before, asserted that a significant proportion of the questions focused on grammatical knowledge, a belief that influenced the proportion of time she spent on grammar instruction.

In response to these state standards and assessments, the four teachers typically dedicated a few minutes of each period to grammar instruction by posting and annotating sentences on the board. To be sure, the *sentence* was not the only text that teachers used to promote grammar instruction. At times, students drew illustrations of these sentences, cut out photographs from magazines to demonstrate concepts such as compound subjects; moved objects *above, on,* or *beneath* something to illustrate prepositional phrases, moved their bodies into particular sentence configurations after each person had been given a word representing a part of speech, and participated in other multimodal grammar-building exercises. At other times, students completed sentence-combining exercises and edited their writing through activities such as adding particular types of adjectives.

Nonetheless, as suggested by the frequency count, the sentence remained the primary text through which the four teachers instantiated grammar instruction. While this type of instruction has long been critiqued for not improving writing (Hillocks & Smith, 2003), it is nonetheless perhaps understandable when seen from the perspective that people usually choose the form of communication that they think will best help them reach a particular end. Wertsch (1998) argued that, in educational settings shaped by high-stakes testing, "The temptation to rely heavily on test questions is quite understandable. Indeed, from this [sociocultural] perspective they must be viewed as quite appropriate and adaptive" (pp. 123-124).

Likewise, if a high-stakes assessment required students to identify individual words in sentences, it does not seem unreasonable that teachers and students would practice annotating individual words in sentences to move toward reaching that goal. This explanation is not intended to tout the benefits of grammar instruction but instead to offer suggestions as to what the frequent use of sentences might have afforded teachers in their English instruction. In the words of Annette, when she was shown the frequency count of her instructional representations and asked to explain the findings: "It's the nature of what we're trying to teach them that requires—like sentence structure, you have to use sentences when you do sentence structure."

Narratives

Dramatists, philosophers, and literary theorists have articulated different definitions of *narratives* (Mitchell, 1981), but according to Bruner (2004), there remains "widespread agreement that stories are about the vicissitudes of human intention" (p. 697). Specifically, narratives trace a human agent with an intention, goal, purpose, or motive as that person performs *actions* in particular *settings* but faces *trouble* in pursuit of her or his ambition (Burke, 1945). Accordingly, across the four teachers' instruction, students read along as Franny sought to become a world-class pianist but was thwarted by her nemesis whose father bought off the judges of the piano contest in *The Rising Star of Rusty Nail* (Blume, 2007); as Phillip sought to survive, with the help of a Black man against whom he initially felt prejudice, after he was blinded and stranded on an island in *The Cay* (Taylor, 1969); as Phoebe sought to heal after her brother's death in *Mick Harte Was Here* (Park, 1996); and as the orphaned Jeffrey sought to find a warm and inviting home in a racially divided city in *Maniac Magee* (Spinelli, 1990). In each young adult novel, students followed a character about their age, evaluating her or his decisions as this character addressed challenges such as the death of siblings and parents, homelessness, racism, the unjust use of power and money, and so forth.

According to Langer (2000), reading literary texts such as these involves "living through the experience," including the exploration of "emotions, relationships, motives and reactions, calling on all we know about what it is to be human" (p. 2). At times, these narratives led to conversations around these big themes as students developed divergent interpretations based on their life experiences (Rosenblatt, 1995). Nancy Rae, for example, held discussions with her students about their experiences with gender inequity as they read *A Strong Right Arm* (Green, 2002), while Annette asked her students if they had known people who disliked others because of their race just as Phillip was initially wary of Timothy in *The Cay* (Taylor, 1969). Alice's students described times when people in positions of authority had used their power over them, just as the teacher from *Eleven* did to Rachel when she ordered her to wear a sweater that was not hers (Cisneros, 1991).

Francine's students used the novel *Maniac Magee* to discuss larger themes of human motivation and action:

> *Francine* [pointing to a quote on the board and reading it]: I felt fear. In humans fear turned into anger, hate. Violence.
>
> *Student*: I saw a movie like that last night. It was called the *Andromeda Strain.* And people started killing themselves 'cause they didn't want to die from it.
>
> *Francine*: This is what I want us to think about today, this idea, fear in humans turns into hate, anger, violence. What do you guys think about that?

Francine's students responded with a variety of responses: one student hit her sister because she was scared of her; another mentioned that people can punch holes in the wall when they are angry; another mentioned Brad Pitt's desire to kill the king in the movie *Troy,* while another student mentioned when a death happens in the family, "the way it made you feel, you try to make other people feel the same way you do." The conversation concluded when Francine posed the following question:

> Why do we need to talk about violence?
>
> *Student:* Because you brought up the question.
>
> *Francine:* Okay, so why is that question important? Why did I even ask it, I wonder?
>
> *Student*: Because it happens.
>
> *Student*: Because violence is what makes us humans.

Student: No it doesn't.

Student: It's literally impossible to go out and not have violence. You're going to have time in your life when you have violence. You go out, you have violence, and you get over it. That's what makes us human.

Francine: Let's look up violence in the dictionary.

Student: Rough force or action; harm injury; unlawful use of force.

Francine: So using force in a way that's not right. Now we know, violence, hurting, harming, forcing in a way that's wrong. Do we have to be violent?

Student: Not all the time, but the war on terrorism we're fighting right now, we're still fighting them. If somebody does something violent towards you, you're going to want violence back, and that's just what makes us humans.

Francine: If someone harms you and it hurts you, even if they never touched you, my first reaction most of the time is I'm going to hurt them back. I see that. Now, because we are human and that's our struggle is to have some management over our anger, like [Student] said before, whether or not you take the next step and you're violent back, I don't think that part we have to do.

In this example, Francine directed her sixth-graders' attention toward questions of human motivation by asking what causes people to be violent, with students asserting that death in the family, being hurt first, group tensions, fear of illness, and fear of being taken away can all lead people to commit acts of violence against themselves or each other. Although students connected violence in some way to the characters of *Maniac Magee,* they also made connections to global events (war on terror), to other stories (the movies *Troy* and the *Andromeda Strain*), and to their own family relationships (hitting my sister). In this way, the novel provided a platform for students to draw from many sources—all of which illustrated human motivation—to debate claims about “what makes us humans,” to use one of her students’ phrases.

Along with reading narratives to discuss larger themes of human motivation, students were also expected to read narratives for enjoyment. On a regular basis, students were given class time to read books of their choosing, often after hearing the teacher and other students share about novels they had read. A lover of young adult literature, Annette had read all of the Newbury-award winning books over the past 30 years and required her students to read a novel by one of the Newbury authors of their choosing, which they could borrow from her extensive classroom library. Nancy Rae’s department, too, owned sets of high-interest novels that students borrowed and discussed in small groups.

As students read independently-selected novels, the teachers asked them to perform tasks indicating their affective responses to the novel, such as *Love it. Copy your favorite sentence*, and *Find a word from the selection that you like.* These tasks led to whole-class discussions about another aspect of novels: Not only were they written with a particular global structure, following characters in pursuit of a goal, but this structure was realized at a micro-level through specific kinds of descriptive language, with students identifying words and phrases such as *dimwitted mushroom muncher* and *trousseau* among their “favorites” in particular lessons.

Another common approach to teaching free-choice novels was by asking students to perform certain cognitive tasks as they were reading. Annette, Nancy Rae, and Francine regularly asked their students to *predict, question*, *summarize*, *visualize, connect*, *evaluate,* and/or *use context clues to figure out unknown words* in relation to the novels they were independently reading. Annette’s students kept track of their use of these strategies with a journal, which they shared and discussed with their friends who were reading the same books, while Nancy Rae's students tracked their thought processes by recording them on sticky notes, which they then posted on a bulletin board divided into subsections devoted to each comprehension strategy (see Figure 3.3). Francine's students accomplished a similar objective by writing predictions and evaluations about the novels they were reading on a wiki-page. A final common approach to teaching narratives entailed discussions of how different types of narratives compared to each other as well as to non-narrative texts as students made graphic organizers comparing their similarities and differences.

In all, as these descriptions and the frequency count suggest, teachers believed they could accomplish their overall goals for reading narratives—aesthetic enjoyment, inquiry into "what makes us human," comparing genres, noting literary features, and teaching the regulation of thinking processes—largely through the mode of written words and through discussions in response to this mode. In fact, English was the only discipline wherein students read hundreds of pages (novels) that included no images, numbers, tables, and other forms of representation, whereas every coded page of textbooks in other disciplines were multimodal. In this sense, publishers, too, seemed to think that engaging with a novel did not require images in the same way that understanding symmetry or lunar phases did.

Why was English a word-based discipline in its emphasis on reading and discussing narratives as a primary text? Any answer to this question would be speculative, but a few of the teachers' comments point to possible explanations. As noted before, English standards explicitly required attention to the *form* and to *written language*, including the descriptive language of narratives, while not requiring the same kind of attention to the features of images. For example, as part of their emphasis on teaching comprehension strategies for approaching narratives, the four teachers helped their students to "determine the meaning of unfamiliar words by using word, sentence, and paragraph clues" (Georgia Performance Standards, 2006, ELA 6R1). While some strategies for approaching written texts, such as *visualizing,* explicitly require the transformation of one mode (writing) to another (image), the everyday human experiences encoded in narratives arguably did not necessitate images in the same way that an unfamiliar object (e.g., crystal structure) does.

Nancy Rae explained her heavy reliance on written language in English as opposed to her reliance on other modes in earth science wherein written words only comprised 43% of total representations: "In language arts, you're focusing more on the language, so you're going to be looking at it, whether it's reading or writing." Annette, too, while explaining her use of images in English (8% of total representations) as compared to social studies (25% of total representations), asserted that she would rather have her students "use their imaginations" to generate their own visualizations of characters, rather than showing them images related to literature. She elaborated: "Occasionally we use maps to show where things [in novels] are, but how do you show Narnia? Sometimes you do use maps, but not as often as in social studies where you are so, 'This is where it is, these are where the mountains are, why do you think you can't go from here to here?' It's just the nature of the subjects."

Similarly, Alice, when shown the frequency count of the representations she used, explained her results in the following terms:

> That's what language arts is: reading and writing….Like if I were to read a short story, a lot of times in the book they'll have a picture, but sometimes I ask myself is it worth discussing the picture? Is it going to teach them anything? And I think that's what happens with language arts sometimes is your focus is on trying to teach them the plot of a story. Is the picture really going to teach me a plot?

In all, then, the four teachers asserted that, due to the discipline's focus on the medium of written language itself, a medium that was emphasized in state standards as well as on the middle grades writing assessment, they used written language as a primary method of instruction.

Moreover, for many people, writing in and of itself is a powerful mode for mediating and expressing emotion, thought, and experience (NCTE/IRA, 1996). The author (2011) has argued elsewhere that one reason that English can seem more personal than other disciplines is precisely because students can follow a narrator through life experiences, listening in on his or her inner thoughts and decision-making processes in response to these experiences. Written words are thus useful, not only because they are the medium of the standards, but because in and of themselves they can build powerful understandings of the human experience and can enable students to clarify and express their thinking (Langer & Applebee, 1987).

Images

The four teachers' relatively word-based instantiation of English is not to say that images cannot or should not have a more prominent role in this discipline (Flood, Heath, & Lapp, 2005). Instead, their role is perhaps somewhat different from the role of images in other disciplines. Kress (2003) has asserted that the fundamental characteristic of this mode is that it is governed by the logic of space, an affordance that is indispensable to spatial reasoning required by the goals of earth science and mathematics (National Research Council, 2006; See also Chapters 2 and 4). In English, however, teachers' goals did not generally require spatial reasoning. One could still develop in-depth understandings of a character's psychology without a precise understanding of his spatial position in relation to objects in the room. The existence of art, however, is a powerful testament for other possible affordances of images, such as their potential to provide people with aesthetically moving experiences and new understandings that cannot be reduced to spatial relationships alone (Hopkins, 1998; Wagner, 2003).

Zoss, Smagorinsky, and O'Donnell-Allen (2007) described this potential for color, line, and other aspects of images to serve as "emotional and spiritual mediators" for many students (p. 26; cf. Fleckenstein, 2002), enabling them to think about themselves and literature in generative ways that "serve as the basis for continued reflection and development of thinking" (Smagorinsky & O'Donnell-Allen, 1998, p. 221). Eisner (2002) similarly argued that images, when integrated into English curricula, "can enrich one's life" and "develop the mind by giving it opportunities to learn to think in special ways" (p. 10).

Along this vein, Siegel (1995) drew from Suhor's (1984) earlier work to offer a description of the mechanisms by which images can help the mind to think in these "special ways." She argued that *transmediation,* or "the act of translating meanings from one sign system to another" (p. 455), is generative by its very nature because it requires students to develop deeper understandings as they invent connections between two or more sign systems and the concepts they are studying. As an example, she described two students who did not understand an article until they drew and labeled a sketch that served as a graphic organizer to show how different concepts in the article were related. This act of transmediation, she argued, provided students with "an entry into the text" (p. 468).

It is noteworthy to point out that Siegel lauded transmediation in large part for its ability to provide an entry into *written texts* (cf Whitin, 2005). Images in English were largely, though not exclusively, used to illustrate a previously written text or to spark students' thinking prior to creating written texts. In this way, images' secondary position in relation to written words was perhaps further instantiated in this discipline. Unlike earth science, in which images and other modes usually co-represented something in the *world*, and unlike mathematics, in which images and other modes usually co-represented an *abstraction* such as mathematical operations, images in English oftentimes were used to mediate students' understandings of *written texts*.

Several examples will illustrate how images were used with the end goal of producing writing or with the end goal of understanding written texts. Annette began one lesson by giving each student a feather and instructing them: "Okay, everybody, blow your feather….Blow it in the air. See if you can catch it on your elbow. See if you can catch it on your knee. See if you can turn around and catch it."

After showing them her own image and poem (see Figure 3.4), Annette instructed students to write ten adjectives, six -ing words, and a simile, combining them together to form a cinquain poem illustrated with an image. When asked why she included the illustrations in this lesson, Annette replied, "Because I wanted them to feel the poetry instead of just being cold and hard. And just make it—for some of them, it just makes it more enjoyable," adding, "I've never had a class that didn't enjoy it, even big old football player boys just giggling. I just let them pure play with it, too." Annette's use of the words *giggling, pure play, feel the poetry,* and *more enjoyable* indicate her belief that non-linguistic texts can mediate students' experiences with written texts in ways that contribute to their aesthetic pleasure. Her response also indicates that her purpose for using the image was to help students feel *poetry*, emphasizing the written text as the end goal.

Francine similarly used images to improve her students' writing. After her students had written a first draft of their personal narratives that, for the most part, did not include "a whole lot of interesting detail to pull me in," she showed her students a single line shaped like an ocean wave. She gave the students thirty minutes to use markers, colored pencils, construction paper, and other materials to transform the line into an eye-catching picture. Students responded by creating colorful, multi-textured images of a hill, an ice cream cone, a ninja, and an umbrella, among other objects.

"Right now your writing is here," Francine told them, pointing to the original line. "This is what you have now. You have something, and there is some shape to it, but now we need to get it to this [pointed to a student's drawing], and we need to get it to this [pointed to another student's drawing]." Francine drew parallels beteween the process of adding details in illustrations and adding details in writing, asserting that, just as in drawings "we can go from something that's basic and simple and turn it into whatever else by using color and detail," students could flesh out their personal narratives by adding more sensory details. Students then used the same principle they had practiced with the image to revise their stories.

Along with being used as a precursor to *writing*, images were also in textbooks used to illustrate many of the *written narratives* that students read (see Figure 3.5). Teachers did not usually draw students' attention toward these images, however, with only three exceptions throughout the school year when students used these images to make predictions. In this way, textbook images were not used as a source of information as they were in mathematics and in earth science.

Students also drew pictures in response to their readings, as when Annette's students visualized scenes from their self-selected Newbury books as part of their literature journals. Francine's students drew sketches of Harrison Bergerson (Vonnegut, 1968), a protagonist who rebelled against a dystopian government. Francine emphasized that their depiction should convey Harrison's internal characteristics as well as his external physique, a task to which some students responded by drawing him as a brave, handsome, and muscular man who powerfully defied his society and to which others responded by drawing him as a man laden with government-issued "handicaps" such as braces and weights that he could never effectively remove. Students then shared their images in groups, explaining why they illustrated the character as they did. This instance, too, illustrates how images could be used to mediate students' experiences with *written texts*—in this case perhaps by gaining insight into Harrison's heroic or tragic qualities. The frequent inclusion of drawings in this discipline, used four times more often than photographs, indicates images' grounding in imagined worlds such as those invented first by authors' writing.

Less frequently, students read images under the assumption that they connected with a referent that would be observable in the physical world. For example, Alice's students read historical fiction about the explosion of Mount Vesuvius in 79 AD, and they used a map of the city to locate different events from the story. However, in accordance with the discipline's focus on *form* rather than *content,* Alice's primary goal was not for her students to learn about what was represented by the map, but to learn about the characteristics of historical fiction—specifically, how the story they read included accurate facts about Pompeii. For this reason, Alice ranked the map as less important than the story in this lesson.

In all, the four teachers in the study did not instantiate the discipline of English as one that relied on images as heavily as it did on words. The teachers used images as pre-writing tools, as a means for building students' comprehension and enjoyment of literature, and in other ways, but even in many cases where images were used, the teachers' primary goal usually entailed the production or comprehension of written texts as indicated by suggested by the frequency counts indicating methods of instruction (Table 2) and assessment (see Figure 3.6).

Gestures and Embodied Representations

Arguably, the four teachers likewise did not use embodied representations and purposeful gestures, which comprised 6% of total texts, as a central means of instantiating English. *Action* gestures, or the mimicking of a human's actions, occurred with most frequency (see Figure 3.7 for a bar graph comparing types of gesture). As this type of gesture suggests, purposeful hand and body movements were largely used to act out parts of a written text. In a lesson on figurative language, for example, Alice read aloud from *Swish!* (Martin & Sampson, 2000), an illustrated children's book about a girls' basketball game, featuring literary devices the students had recently been discussing.

"Dribble, dribble, dribble, Janet passes off to Kim," Alice read. "Outside shot goes off of the rim. Jumping high into the sky, swish! [Lifts right arm in an upward motion and folds fingers down over palm to mimic how the basketball player made a shot.] Swish is an example of what?"

Student: Onomatopoeia.

Alice: Onomatopoeia, a word that is a sound.

Student: That's a basketball.

Alice: It's the sound a basketball makes. What is dribble dribble dribble? [moves right hand, flat palm facing downward, up and down in a "dribbling" motion].

Student: Onomatopoeia.

Student: Repetition.

In this example, gesture was not essential to reaching the instructional objective, understanding literary devices, but this instance nonetheless showed how hand movements could be used as a quick, ad hoc means to illustrate the action of a narrative. As other examples, students scratched their arms to illustrate incessant itching, wiggled their hips to represent a moving skeleton, put their hands on their forehead to feign illness, and likewise used physical responses to mimic the action of what they were reading.

At times, students and teachers also embodied characters, such as when Nancy Rae wore a long blonde wig and an apron, pretending to serve meals as part of a model “book talk” in which she told the story of a character’s life as though she were that character. Her students, too, each dressed as a character from their self-selected novels and told the story of their lives from that person’s perspective. As a final example, Francine’s students drew cards from a stack, each one containing a *setting,* a *conflict,* or a *character,* and they worked in groups to act out a story using the cards they had selected, including scenes where students pretended as though they were jumping on the moon (through making large and slow steps) and shooting an alien (through a jolting movement in one outstretched arm). Students later wrote a Choose Your Own Adventure story based on their group skits.

Action gestures and embodied representations in English can be tied to *drama,* a tradition with a long history in the discipline as students read and perform texts (Applebee, 1974). The benefits of drama in English have long been cited as providing deeper affective engagement with written texts—from canonized scripts for Shakespearean plays to contemporary novels—leading to claims that roleplaying or embodying characters can help students to “*be* the book” (Wilhelm, 1997) and get “*into* the story” (Miller & Saxton, 2004) as they try to act and speak as a character would (Franks, 2008; Schneider, Crumpler, & Rogers, 2006).

Much of the argument that was made about images in English can also be made about gestures in English. Whereas in disciplines such as earth science gestures can be essential for showing *movement* or *spatial position,* spatial reasoning did not play a role in the four teachers’ daily essential questions. Consequently, the affordances of gestures in English instead move to discussions of aesthetics, engagement, and embodied ways of knowing and expressing the world. Like images, gestures were arguably also instantiated as being supplementary to written texts in the sense that they were most commonly used to promote students' engaged *understandings of written narratives* as the end goal.

Texts in English: A Summary

Flood, Heath, and Lapp (2005), in a handbook of research on integrating the visual arts into "literacy" classrooms, have issued a call to "[bring] the visual arts into a central place in literacy and language education" and to disrupt "literacy educators' exclusive focus on learning as reading and writing" (p. xvi.). In one sense, the research described in this book confirms the assertion that English as a discipline can be very word-focused as compared to other disciplines. However, rather than dismissing word-focused instruction as limited teaching, the reasons why the four teachers chose to instantiate English as a word-based discipline deserve a second look, especially because the same teachers used non-written texts as 49% of their instruction in social studies and non-written texts as 57% of their instruction in earth science. Nancy Rae, for example, purposefully used gestures in 66% of instructional episodes in earth science, whereas she purposefully used gestures in only 15% of instructional eposides in English. Instead of criticizing this lack of gestures, this research tries to understand why English might have been instantiated in this way through looking at this mode's affordances in relation to what the teachers sought to accomplish.

As a discipline wherein standards direct teachers to focus on the *form* of texts, often specifiying that this form should be *written words* with particular characteristics such as varied syntax, word choice, and subject/verb agreeement, it makes sense that the teachers would value written language as a key means of communication in order to draw students' attention toward these linguistic forms. This research does not suggest that English *should be* instantiated as a word-based discipline, especially when considering the proliferation of multimodal digital texts that students read and generate, and especiallly when considering that modes such as music, drama, and drawing are powerful mediums through which many students build and express understandings of themselves and the world.

This research does, however, potentially highlight a tension that Marshall (2008) described in his critique of many standards documents in English: "There is a serious incompatibility between the current standards and assessment movement and our long-established, research-supported best pratices in the teaching of literacy" (p. 122). When his statement is approached from a semiotic lens, this research perhaps suggests that, when standards and assessments explicitly describe and evaluate English in terms of a series of written texts, it is understandable why teachers would privilege this mode as the teachers explained in their decision to focus on written language.

Reading and Representational Practices Specific to English

The following section will describe reading and representational practices specific to English. As noted before, these practices were not always multimodal, but they are still important to understanding how reading and representing were set apart in English as compared to other content areas. Using these goals for the discipline as a basis, Chapter Five articulates a vision of how multimodal texts might be used to help students achieve the same goals. Reading practices specific to this discipline included (a) reading and writing to reflect on identity, including personal values used to guide decision-making; (b) reading and writing with a focus on form or process; and (c) reading texts aloud.

Reflecting on Personal Values and Identity

English as a discipline provided students with opportunities to share their preferences and interests; to discuss the quality and nature of their personal relationships; to consider how cultural norms shape their own and others' perspectives and actions; to compare their personal morals, values, and beliefs—as standards or arbiters for making decisions—to the morals, values, and beliefs of real and imagined others; and to engage in other issues related to explorations of identity. An example from Alice's instruction illustrates how she encouraged students to reflect on their personal relationships, aesthetic preferences, and things of importance to them.

In a lesson about themes in poetry, Alice asked her students to choose two of their favorite songs, both addressing the same subject (e.g., love, friendship), and to bring the written lyrics to class. Alice introduced the lesson by playing her wedding song, *Bless the Broken Road*, as she projected the written lyrics on the screen. Just as students had to explain the reason behind why they chose their own songs, Alice told her students that she chose her song because:

> The words describe my relationship with [my husband]. It's a very personal song because it describes who we are. This reminds me of when Nick and I got married. When you choose a song, it could be just because a song makes you smile or makes you feel good. When it says why did you pick it, there's no right or wrong answer to that question. When I look at that song, you have to remember what a broken road looks like...One of the most important words or phrases to me is the idea that there's a road that's broken and you don't know what way to go. What [important words] do you guys see?
>
> *Student*: The Northern Star.
>
> *Alice*: Do you know the history of the Northern Star?
>
> *Student*: It always points North.

Alice: Why would that be important?

Student: Because way back in the day,

Student: the 80s

Student: Biblical times

Student: Jesus was born and Herod sent three wise men to kill him, and people followed the Northern Star to give him gifts.

Alice: The Northern Star was the way that he showed me how to be. My relationship with Nick could be something like he grounds me. He is my opposite in a lot of ways. He's very laid back; he's very roll with it. When I listen to that part, I think to myself, he's the other side to me that helps me to be normal. He's the person that I go to the most. Are there any other words or phrases in there that you think are good ones? What are some of the phrases that are important to the overall meaning?

Student: Where it says *pointing me on my way to your loving arms* because it's about him loving her. And that goes back to the Northern Star directing her into his loving arms.

In this exchange, Alice established several practices as being legitimate in English. First, she asserted that students can choose a text for further exploration in this discipline simply because it "makes you smile or makes you feel good." Second, she indicated the discipline's potential to enable spaces for students to evaluate and reflect on personal relationships. Students later followed Alice's example in discussing their own self-selected song lyrics, such as when one girl talked about not trusting her friends after playing TLC's *What About Your Friends?* for the whole class. Furthermore, Alice established that English can engage students in questions of values that guide people, just as the metaphorical Northern Star guided the lyricist, and just as Alice's husband served as a guiding star whom "she went to the most."

Nancy Rae also asked her students to reflect on their personal values and characteristics when she introduced a unit to her students in the following terms:

> We're going to be talking about *who am I?* We'll be talking about our factors, different abilities, what do you like, your mannerisms, cultural backgrounds, experiences. All of these are attributes that help to define who we are as a person. This starts when we're a baby and continues until we're adults…When you think about who you are, ask yourself these questions: What do you like to do, what am I good at, and how do I express myself?

Throughout this unit, Nancy Rae used informational texts about people from different cultures, such as a text describing gender roles in ancient Japan, to engage students in the overarching question, *How does our culture affect who we are?.* This unit included an inquiry into how the students' parents and friends perceived them because "By looking how you're viewed by others, you can learn about yourself." She then asked students to write their own personal mission statement after reading the school's mission statement as a model.

In these two descriptions of Alice and Nancy Rae's instruction, song lyrics, informational texts, and a mission statement were used to bring out issues of identity and values. As indicated before, narratives, too, are especially promising texts for bringing out these kinds of issues. When considering how comprehension strategies might be unique to different disciplines, therefore, one important characteristic of English is its potential for students not just to *make connections* in a general sense—such as when Alice's students used their background knowledge of volcanoes to make inferences about the type of volcano that destroyed Pompeii—but to connect to the choices that individual characters make against a backdrop of complex personal circumstances. For instance, while reading *The Dogs of Pompeii,* Alice's students wrote a list of five things they would risk or sacrifice, and they identified for whom or what they would sacrifice those things.

Students shared their lists, comparing what they were willing to risk to each others' answers and to the fictional dog who sacrificed his life for his owner by running into an impending pyroclastic flow. As another example of evaluating characters' decisions, Francine's students discussed whether Maniac Magee's refusal to eat was the same thing as committing suicide (Spinelli, 1990), and they justified their reasons for thinking that the orphaned Maniac had the right to run away while two other characters did not have the same right. These examples illustrate narratives' capacity to encourage students to think about their own and others' personal decisions in the face of complex and contextualized circumstances.

Reading and Writing with a Focus on Form or Process

To some extent, each discipline can include explicit discussions about the structures of texts within that discipline, an assertion that is a major tenet of proponents of disciplinary literacy instruction. English as a discipline, however, was unique in the extent to which it focused on the forms of written texts, a focus that at times superseded discussions of the texts' meaning. This focus on form at times enabled students to select texts regardless of their content.

Francine's students, for example, discussed the features of informational texts, including glossaries, indexes, photographs and captions, and headings. Students then read informational texts on subjects of their choosing—ranging from planes in World War Two to poisonous snakes—and identified how each text used these features. Similarly, Nancy Rae's students read novels of their choosing and performed tasks such as identifying the protagonist, the antagonist, an internal conflict, and an external conflict. In these examples, students were not assessed on what they learned about planes or on what overall meanings they derived from the novel.

Instead, in these particular cases, teachers signaled they valued students' awareness of the features of different genres. In sum, unlike other disciplines, wherein texts had to be about a particular something, English provided spaces wherein students could read and write texts about anything as long as they discussed approaches for reading those texts or characteristics of those texts.

A focus on form and process—rather than writing about a particular body of content—likewise characterized writing instruction. In one lesson that emphasized *organization* and *pre-writing*, for example, Nancy Rae worked with her students to generate two lists on the board: one list titled "NOW" that included a list of activities that students liked to do in their free time, and one list titled "1910" that included a list of activities that 11- and 12-year olds would have participated in 100 years ago. An excerpt indicates how she used this activity to teach pre-writing.

Nancy Rae: What else do you do during your free time, [Student]?

Student: Play video games. [Nancy Rae writes •*play video games* on the board as the next item on the list.]

Nancy Rae: Okay. What do you do, [Student]?

Student: I play with my little brother. [Nancy Rae writes • *play w/ friends or family* as the next item on the list]. Okay, how about you, Nancy?

Student: I play on the computer.

Nancy Rae: Okay, so what were some things that you think people did, kids your age did during 1910 when they had free time?

Student: I think they might have played basketball and baseball.

Nancy Rae: Okay, so they might have had some sports, right? [Nancy Rae writes • *sports* on the board as part of a new list titled 1910.] Or some type of outdoor games, right? [Nancy Rae writes •*outdoor games* on the board.] What else would they have done, [Student]?

Student: Played marbles inside.

Nancy Rae: Yeah, like board games, right? Indoor games, marbles, chess. [Nancy Rae writes •*indoor games* as the next item on the list.] What else? [Students continue to generate items on the second list.]

Nancy Rae: Okay, now let's look at things that are the same. So we have *write,* that's the same, we have *read*, *sports,* okay. We have *play with family or friends.* We have *exercise,* okay [underlines each common item on the board in green as she reads it]. But so what skill are we really doing over here [sweeps hand over the two lists]?

Student: Compare and contrast.

Nancy Rae: This would be a great pre-writing activity, wouldn't it [Nancy Rae moves her hand over the board] if you were trying to compare and contrast what people your age did in the 1900s or 1910 and what you guys do now. Now compare means what? How could I tell a Kindergartener what compare means? When I'm comparing, what does that mean?

Student: We're seeing how they're the same.

Nancy Rae: Right, so compare means seeing how they're the same or similar, [puts flat palms together while saying similar] right? And then contrast would be what, everybody?

Student: See how they're different.

Nancy Rae: See how they're different, right? What graphic organizer lends itself beautifully to compare/contrast, everybody?

Student: Venn diagram.

Nancy Rae: Venn diagram [Nancy Rae draws a Venn diagram on the board], right? So what we could do is we could actually do a Venn diagram and we could put all the different things on the side [points to the two outside circles in the Venn diagram] and the things that I underlined in green in the middle [points to the middle of the Venn diagram], right?

In this exchange, Nancy Rae explicitly modeled two possible pre-writing activities with her students: brainstorming and organizing ideas by generating lists or by using graphic organizers. In explaining her purpose for the lesson and as indicated by her essential question, she asserted that learning processes for writing, rather than learning about children from the 1900s, were her goals for the lesson. In both writing and reading, then, the discipline focused on forms of texts and processes for approaching them.

Reading Aloud

On a regular basis, all disciplines included teachers and students reading aloud. From word problems in mathematics, to textbook sections in earth science, to informational paragraphs displayed on the interactive whiteboard in social studies—reading aloud provided teachers and students with a common point of reference at the same point in time, allowing teachers to pronounce and clarify unfamiliar words. English was distinctive, however, in its emphasis on the *sound* of oral language as teachers ranked spoken texts of highest importance in particular lessons, a type of ranking that did not occur in any other discipline.

In a unit on figurative language in poetry, for example, Annette asserted that her oral readings of poetry were more important than the written poems she provided to students, explaining, “This particular lesson, I did want them to hear and read the poems so they could get a feel for the rhythm…I almost think hearing the poems is—you cannot teach poetry without modeling good poetry being read aloud. There are a lot of things you can do without reading them out loud, but poetry is not one of them." The discipline's emphasis on form—which at times included literary techniques related to sound such as *onomatopoeia, alliteration, rhythm,* and *rhyme*—required students to *hear* the language of texts rather than just read the language.

Dialogue was a second domain wherein reading aloud was especially important. Annette asserted that it was important for her to read *The Cay* aloud to her students, at least initially, because Timothy's West Indian accent was difficult for the students to understand in print. In a lesson whose essential question was *Why is reading orally with speed, accuracy, and expression important?,* Nancy Rae's students split into two groups, each of which had a different reader's theater script about a popular children's book. In this lesson, students did not discuss the content of the story as they read the characters' speech, but instead they received coaching from Nancy Rae on points such as, "You have to be more enthusiastic" and "You've got to have some attitude, girl." She continued, "If you're the pumpkin, you're not just going to go *boo, boo* [speaks each word briefly in a low tone and quiet voice]. You need to go like *booooooooo! booooooooooo!* [draws out each word, speaking loudly, in a multi-tonal voice including a high falsetto sound]."

Part of the discipline's focus on the medium of language, then, included a focus on words' sounds. Although not all lessons emphasized the quality of oral speech, this discipline was nonetheless distinct in teachers' occasional objectives of reading with emotional expression, listening to cadence and rhyme, and otherwise attending to the sounds of oral speech as a primary goal of individual lessons. Graff (1987) noted the discipline's historical roots in verbal rhetoric, extending back to Greek orators, bards, and playwrights who emphasized form of delivery as well as content in speeches, poems, and plays. This tradition was present in the four teachers' classrooms as they supported students' communication skills in the areas of reading with expression or producing written texts that sounded aesthetically pleasing when read aloud.

Critical Literacy Instruction in English

Given the discipline's sanctioned space for articulating and evaluating others' and one's own life choices, including the values and factors that contribute to these choices under complicated circumstances, English seems rife with possibility for critical literacy of a personal kind—the kind that requires students to ask questions about their own decisions, assumed life trajectories, beliefs, and relationships. As students consider and create projected futures, their beliefs about appropriate gender roles, about what constitutes "success," about what choices would cause them to be accepted by their communities, and a host of other cultural factors contribute to their decisions. As students examine issues of identity and culture, as they evaluate other individuals' personal decisions, and as they share and debate divergent viewpoints about these issues, they have opportunities to turn a critical eye to some of their own long-held assumptions. Students can reconsider these assumptions in light of characters whose actions are based on a different set of beliefs and in light of discussions with their peers who hold conflicting perspectives. In this way, critical literacy in English can be akin to transformational literacy—literacy that provides a space for students to critically rethink aspects of their own lives as they evaluate the life choices of other people, real and imagined.

Chapter Summary

Many texts in English have a unique relationship to their referents in the sense that building understandings of the text's referents are not always central to the goals of the discipline. For example, just as Francine's students read informational texts to learn about their features, and just as Nancy Rae's students wrote about children in 1910 to learn about the writing process, the actual things to which the texts referred (snakes, children) were relatively unimportant to the goals of the lesson. This characteristic sets English apart from other disciplines wherein a text's referent is almost always important. (That is, students read about *erosion* in earth science to learn about *erosion*.) Perhaps for this reason, the teachers did not always provide multiple representations of texts' referents (additional photographs of snakes or children) because the referents' characteristics could be relatively unimportant to the teachers' goals: teaching the forms of texts and the processes for reading and writing them.

At other times, deep engagement in texts' content did matter, especially when speculating on characters' psychological motivation and issues of identity. Images, body movements, and other modes can be powerful aesthetic, emotional, and spiritual mediators for engaging in these issues. At times, the teachers used non-written modes in this way, but the frequency count suggests that these modes remained largely an untapped resource for expressing meaning. Instead, in interviews, all of the teachers stressed the reading and writing of written language as among the primary goals of the discipline. This value placed on written language was instantiated in the modes they used for instructional and assessment purposes, most of which were written words. This mode was consonant with state standards and state writing assessments.

Table 2

Texts Used in English in 363 Instructional Episodes

Written Words (n=618)	Non-written Texts (n=244)
Sentence: 116	Symbols on existing text: 85
Instructions: 103	Gesture: 43
Narrative: 86	Drawing: 43
List: 49	Graphic organizer: 19
Multiple-choice question: 46	Table: 18
Definition: 37	Photograph: 10
Word: 36	Map: 7
Question: 34	Moving image: 7
Poem: 34	Embodied representation: 7
Informational paragraph: 28	Manipulative: 3
Article: 19	Demonstration: 1
Label: 14	Diagram: 1
Essay: 9	
Criteria: 5	
Informational book: 2	

Characteristics of Literary Texts
What kinds of figurative language can add style to my writing?
How can I improve my writing by adding sensory details?
What is the difference between style, tone, and mood?
How can I apply the characteristics of a fable to my own traditional fable?
What are the characteristics of a modern fable?
What is the difference between a theme and a topic?
How is alliteration used with poetry?
What is the difference between a metaphor and a simile?
What is a hyperbole?
How are onomatopoeia, simile, and metaphor used within poetry?
What is the organizational pattern of a biopoem?
What are the elements of a plot diagram?
What does it mean to identify and analyze characterization?
How does figurative language affect meaning in literature?
What are narrative elements in the selection? (x2)
What's the difference between first and third person narration?
Why is conflict an important part of a story?
How would you compare and contrast fiction and nonfiction?
What is a myth?

Writing Instruction
What does organized writing include?
What persuasive techniques are used in the media?
How can I demonstrate competence in writing?
What can I do to develop my readers' interest?
Why is sequence important to organized writing?
What can I do to engage my readers? (x3)
How can using the three types of adjectives improve my writing?
Can I effectively apply the writing process? (x2)
What are the stages of the writing process?
How can using the writing process improve my writing?
How can I use technology to support my writing?

Reading Instruction
What textual features can help us locate information?
How can we determine the meaning of unfamiliar words? (x2)
How can using textual features help me understand different subject areas?
How can I synthesize different information on the same topic?
How can making predictions show reading comprehension?
How do prefixes affect word meaning?
How can I compare and contrast two texts?
What strategies can I use to acquire new vocabulary?
How can knowing "borrowed" words and Greek and Latin roots help us?
Why is reading orally with speed, accuracy, and expression important?
How am I demonstrating independent reading and acquiring new vocabulary?
What are the clues to figure out an unknown word?

Content of Specific Texts
What is the theme of the *Prince and the Pauper?*
What are the elements of characterization and how can they be applied to *Scout's Honor*?
How does the myth of Ceres and Prosperina explain seasonal changes?
How does pride affect Daphne, Apollo, and Arachne?
Who do you relate to, the Walrus or the Carpenter?
How do the Crane Maiden and Aunty Misery know that it is time to let go of a promise or a sense of responsibility? (x2)
How does fear play a part in the outcome of *The Chenoo*?
Who becomes the "prisoners of fear"?
Where is security?
What are the facts in *The Dogs of Pompeii*?
Who are Melanie and Marshall?
From what narrative point of view is *Maniac Magee* written?

Grammar Instruction
How do I apply the rules of plural nouns?
What are the basic parts of a sentence?
How can I identify verbs and verb phrases?
How can I identify and use pronouns correctly?
How can I identify direct and indirect objects?
What types of clauses are found in each type of sentence?
How important is it to use punctuation correctly?
What clauses make up the four types of sentences?
I can identify compound, complex, compound-complex, and simple sentences.
What are indefinite pronouns?

Figure 3.1. Essential questions in English.

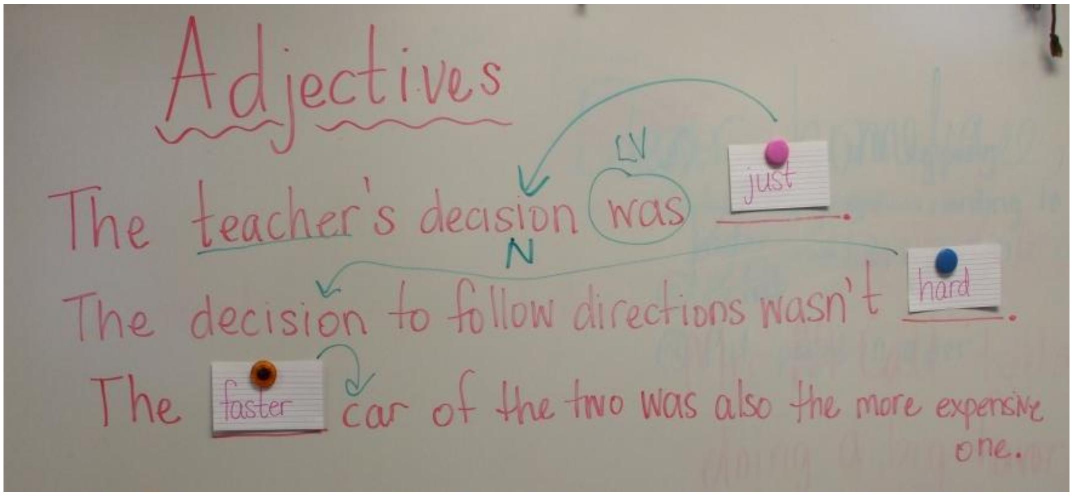


Figure 3.2. Sentence annotated with symbols.

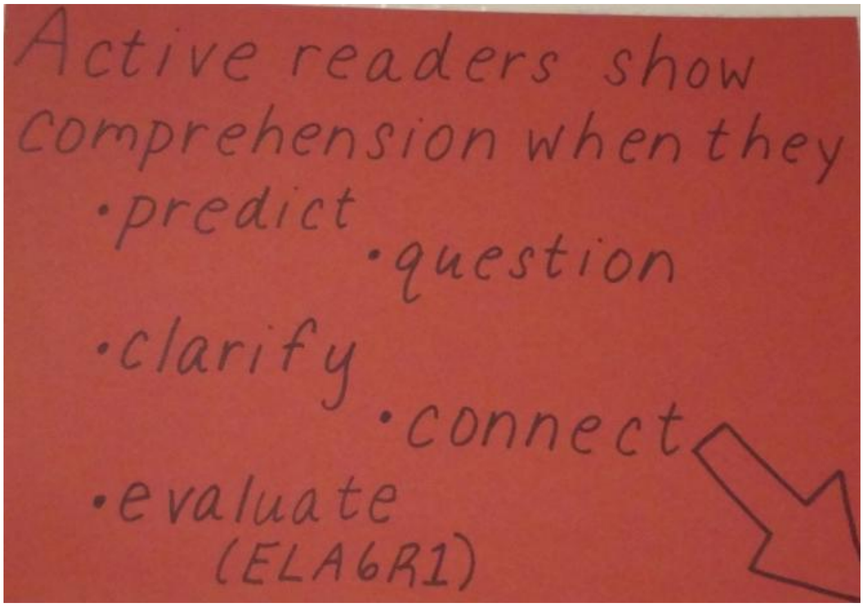


Figure 3.3. Header of bulletin board in English.

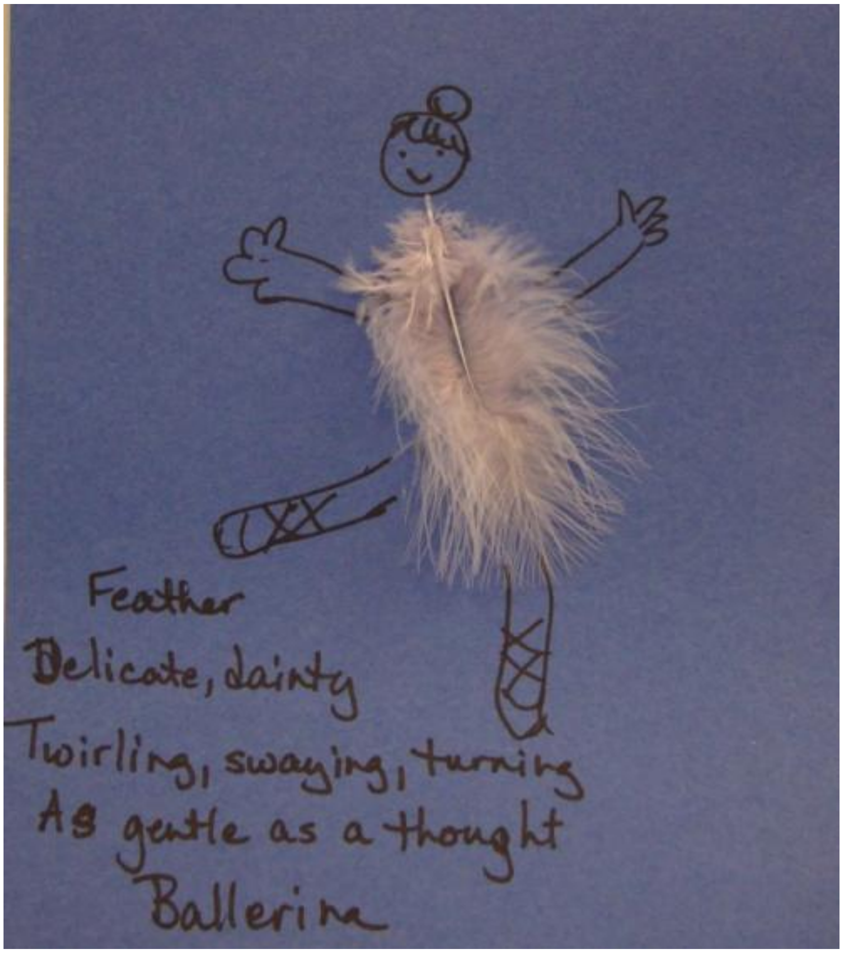
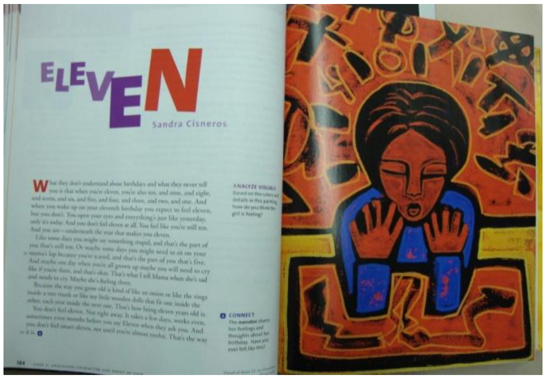
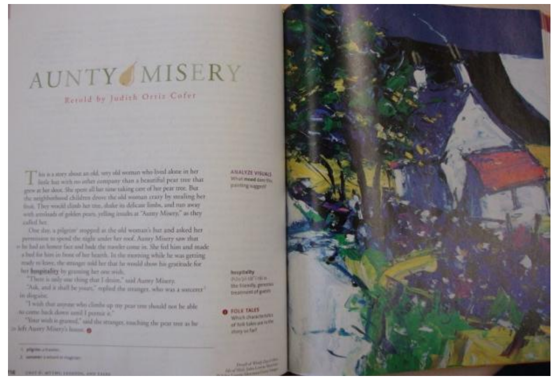
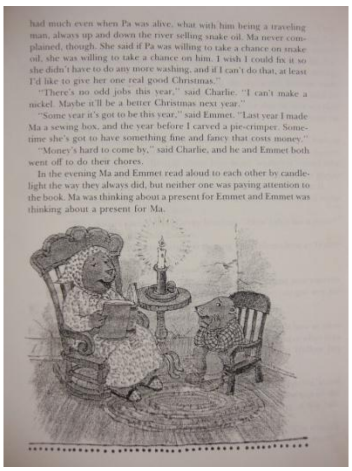


Figure 3.4. Image and poem used in English.







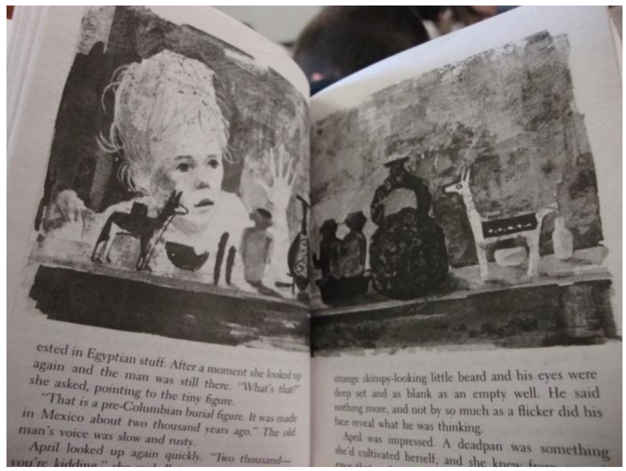
had much even when Pa was alive, what with him being a traveling man, always up and down the river selling snake oil. Ma never complained, though. She said if Pa was willing to take a chance on snake oil, she was willing to take a chance on him. I wish I could fix it so she didn't have to do any more washing, and if I can't do that, at least I'd like to give her one real good Christmas."

"There's no odd jobs this year," said Charlie. "I can't make a nickel. Maybe it'll be a better Christmas next year."

"Some year it's got to be this year," said Emmet. "Last year I made Ma a sewing box, and the year before I carved a pie-crimper. Sometime she's got to have something fine and fancy that costs money."

"Money's hard to come by," said Charlie, and he and Emmet both went off to do their chores.

In the evening Ma and Emmet read aloud to each other by candlelight the way they always did, but neither one was paying attention to the book. Ma was thinking about a present for Emmet and Emmet was thinking about a present for Ma.



ested in Egyptian stuff. After a moment she looked up again and the man was still there. "What's that?" she asked, pointing to the tiny figure.

"That is a pre-Columbian burial figure. It was made in Mexico about two thousand years ago." The old man's voice was slow and rusty.

April looked up again quickly. "Two thousand—

strange skimpy-looking little beard and his eyes were deep set and as blank as an empty well. He said nothing more, and not by so much as a flicker did his face reveal what he was thinking.

April was impressed. A deadpan was something she'd cultivated herself, and she knew from

Figure 3.5. Drawings accompanying narratives in English.

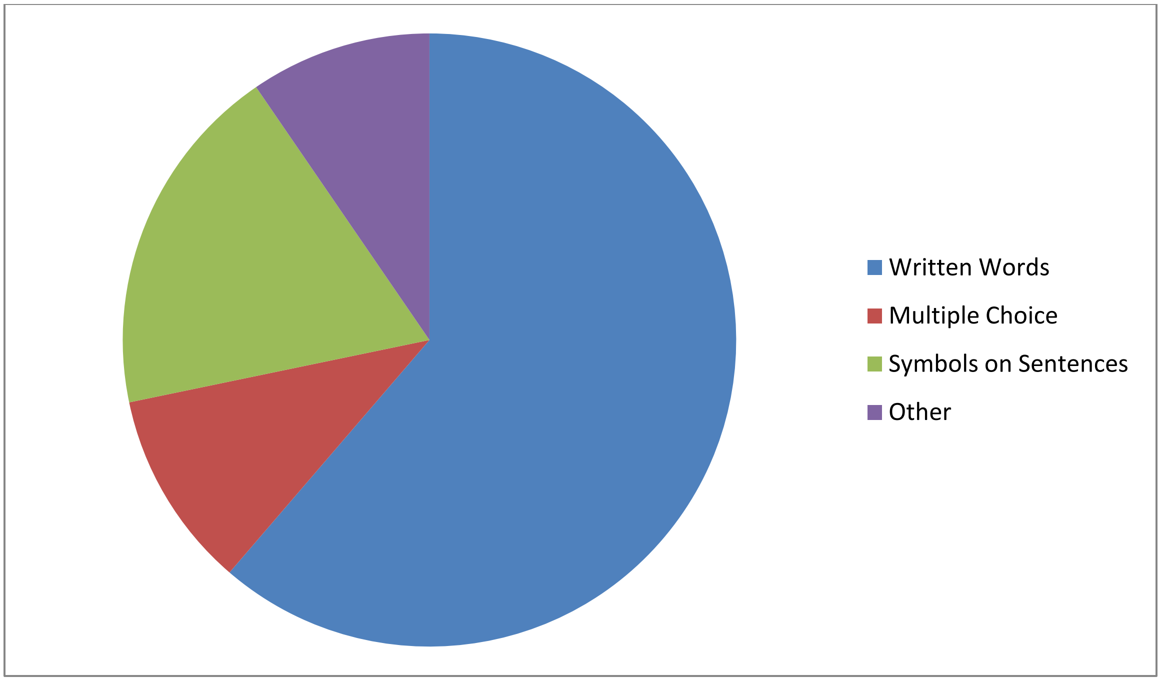


Figure 3.6. Modes used for assessment in English.

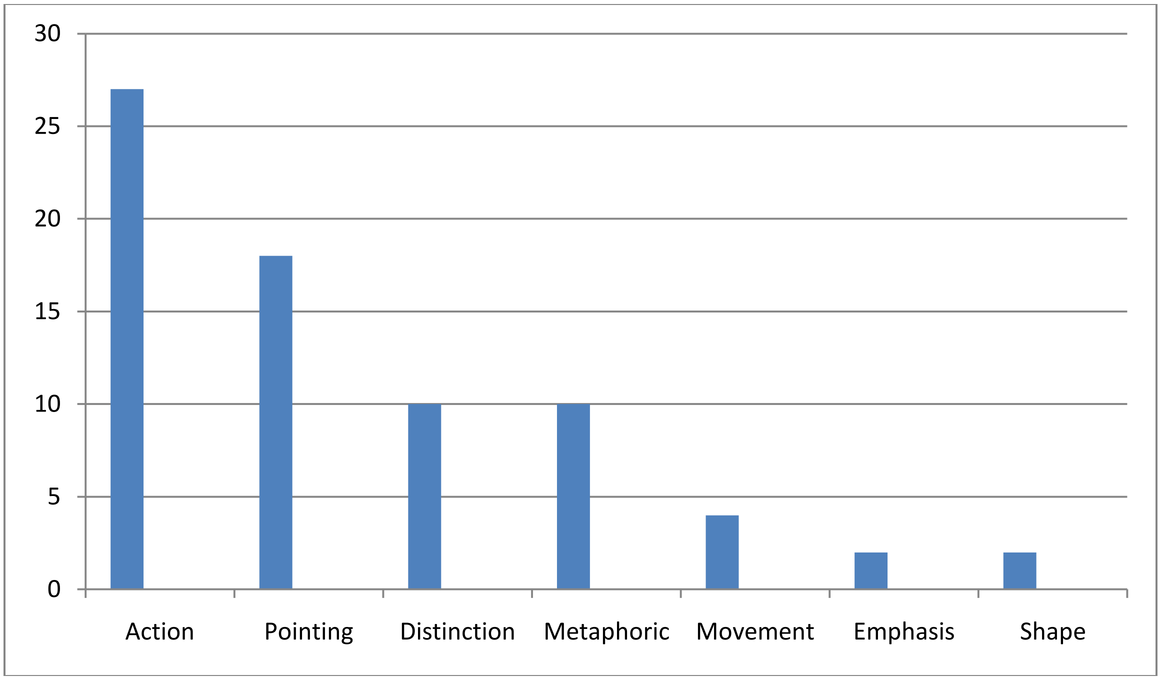


Figure 3.7. Types of gestures used in English.

CHAPTER 4

READING AND REPRESENTING IN MATHEMATICS

A teller compares the number of votes received by each candidate who seeks to be elected to public office. A computer programmer uses binary code to design images and text for display on a screen. A mother chooses an apartment whose rent and utilities she can afford while still providing for the material needs of her children. A young adult “folds” in a poker game after weighing his chances for winning. A vendor decides whether an exchange of goods is advantageous. A seamstress determines how much cloth she needs after measuring parts of a client’s body. An architect builds a structure that is visually imposing and safe for inhabitants. A favorite uncle triples a recipe in order to serve enough food at a get-together for his extended family.

As these examples indicate, ancient and recent applications of mathematical reasoning are foundational to people’s lives both as individuals and as members of society. Whether people are measuring batter, counting votes, relating angles, or calculating probability—mathematical reasoning can be applied to a host of pragmatic, personal, professional, aesthetic, and recreational situations, helping people to make informed decisions, large and small. It is perhaps easy for people to take concepts of *measurement*, *counting*, and *space* for granted each time that they read a road sign denoting a speed limit, each time they buy or sell something, each time they use a calendar, each time they step into a building with confidence that it will not collapse, or each time they play a game with an understanding of its point system. Yet mathematical concepts undergirding these acts have taken centuries to develop and refine.

Anthropologists project that rudimentary mathematics began with hunter-gatherers who recognized that a flock of sheep was *more than* an individual sheep, at times using fingers and drawings to denote specific *amounts* of sheep. Since that time, the development of mathematics in different cultures has been a product of trial, error, innovation, and perseverance as societies and individuals sought to solve a host of problems: architectural feats, fair exchanges in trade, and the development of weapons, to name a few. According to Cajori (1929), the history of mathematical notations is primarily a graveyard of dead symbols as people sought ways to represent and manipulate *number* and *space* that in the end did not allow for maximum efficiency in solving these problems.

One "winner" of these competitions between notation systems is the base-ten Hindu-Arabic numeral system in which the same ten symbols—1, 2, 3, 4, 5, 6, 7, 8, 9, and 0—are used to describe increasingly larger or smaller groups depending on their place value in a given numeral. The symbol 9 can thus represent 9 tenths, 9 ones, and 9 thousands depending on its placement in a given numeral, in contrast to other numeral systems such as the Romans' wherein X always represents 10 regardless of its placement. This base-ten system not only allows for endless representations of large and small numbers, but it also simplifies the algorithms that can be performed with these numbers, when *algorithm* is defined as "a precisely-defined sequence of rules telling how to produce specified output information from given input information in a finite number of steps" (Knuth, 1974, p. 323). For example, if we know the rules for subtracting and adding in the base-ten system, we can use these rules to add or subtract even very large or small numbers.

Swetz (1987) offered another reason for the triumph of the base-ten numeral system in many contemporary societies. Unlike the popular abacus, which did not leave traces of previous operations, Hindu Arabic numerals recorded previous calculations on paper, a valuable asset to early merchants who wanted to ensure that others were not robbing them of money. Lastly, these numerals were much more compact and easier to print on the new printing presses than pictures of beads on wires. Thus, the affordances of the base-ten numeral system, as refined and proven through time, are many: It enables the expression of an infinite variety of numbers with only 10 symbols; it enables its users to easily perform algorithms due to its regular and predictable structure; it is easy to write and disseminate; and it leaves a record of previous operations for inspection by others.

Despite the tremendous popularity, efficiency, and usefulness of the Hindu Arabic system of numerals, however, *number* is not synonymous with this system. Whether it's represented as ten sheep heads on a cave wall, two groups of five tally marks, the word *ten*, ten fingers, the symbol *10*, the symbol *X*, the symbols *10/1* or *200÷20*, the tenth equally-spaced mark to the right of 0 on a number line, or a rectangle with a length of 2 and a height of 5, the entity we know as *ten* exists in what Sfard (2000) has termed *virtual reality*. In this reality, "perceptual mediation is…only possible with the help of what is understood as symbolic substitutes of objects under consideration" (p. 39). That is, though we will never see *ten*, we can build understandings of it through a variety of symbols, images, and words which serve "material avatars," enabling us to apply the abstraction *ten* to real and imagined situations (Ben-Yehuda, Lavy, Linchevski, & Sfard, 2005, p. 28). Mathematical operations, such as addition, are also abstractions to which symbols (e.g., +) have been assigned.

Although contemporary students are the beneficiaries of this efficient and time-worn system of mathematical notation, there are potential educational pitfalls associated with millennia of development in the concept and representation of number. Many algorithms for manipulating these numbers have already been established, and many properties of numbers have already been articulated as non-negotiable 'givens'—such as the statement that "every number other than 0 has a multiplicative inverse, also called a reciprocal, that when multiplied by that number, gives 1." One potential pitfall of this well-developed system, then, is that it can be taught as a series of known statements, rules, and representations, rather than as a process of problem solving wherein students develop their own representations of number, establish their own procedures for solving problems, and justify or explain self-generated solutions.

Likewise, just as mathematicians have developed symbols and principles for representing, manipulating, and predicting *quantities*, they have developed related ideas about *space* and *form.* Euclid famously argued in his *Elements* that a straight line can be drawn from any point to another point, a statement that has served as a foundational axiom for later branches of geometry (Boyer, 1985). These ideas about *space* and *form* are not autonomous from other branches of mathematics: On the contrary, form can be described through numbers as people explain relationships between shapes, angles, and lines. In sum, like notations designating *amount,* representations and rules designating *space* also developed over time as tools that helped mathematicians achieve particular goals. Ideas and representations related to space can also be presented as "givens" to be mastered, rather than as patterns and concepts to be explored.

To counter historically prevalent methods of teaching of mathematics as a series of known procedures and representations, the National Council of Teachers of Mathematics (2000) has recommended an approach to mathematics education in which *problem solving* and *representation* play central roles. As students encounter or formulate problems of their own, they can generate multiple representations in search of their solutions: images, manipulatives, graphs, and/or conventional numbers and symbols, to name a few approaches. This problem solving approach acknowledges that developing proficiency in quantitative and spatial reasoning requires students to reason abstractly and flexibly about *number*, *operations*, and *space*, recognizing that they are not contained within any one representation or method but accessible through many (Hoffman, Lenhard, & Seeger, 2005).

This type of mathematics instruction seeks to foster conceptual understanding, which the National Research Council (2001) has asserted is a major goal of mathematics education. Conceptual understanding can be accomplished in many different ways. Take the case of dividing by fractions, for instance. Instead of simply telling students to “invert and multiply” the second fraction, students can share what they know about division of whole numbers and use that knowledge as a springboard to discuss division of fractions, identify instances when they might have to divide fractions as they split wholes or parts into pieces, use manipulatives or images to devise their own algorithm, and so forth. Researchers (diSessa, 2004; Roth, 2004) have suggested that asking students to develop and compare their own representations , such as prototypes of line graphs, can lead to these deeper conceptual understanding of mathematical ideas.

At the same time, while developing conceptual understandings is a core goal of mathematics, so too is developing procedural fluency and efficiency. Thus, while generating one’s own representations and methods for solving problems is an indispensable component of mathematical reasoning, it is just as important to know how to apply familiar and efficient algorithms and formulas, how to use conventional representations which have been honed over time, and how to use technologies that expedite processes of representation and computation. Although a student may develop her own prototype of a line graph or his own image for dividing fractions, there are reasons why people use Cartesian coordinate planes and conventional numerals and symbols for fractions: They are efficient and precise at what they do, and communities of mathematicians can understand them. Mathematics instruction at its best, then, can solicit student-generated representations, solutions, and definitions while comparing them to those established by mathematical communities, helping students to develop conceptual understandings while at the same time familiarizing them with the conventions of mathematics.

Another important component of mathematical proficiency is *metacognition*, or the active regulation of one's thinking as one solves problems (National Council of Teachers of Mathematics, 2000). Metacognitive students approach a problem strategically, comparing it to simpler but similar problems they have solved, using familiar "benchmark" numbers to estimate answers, looking for patterns and regularities in the representations they are using, and constantly asking themselves if their answers make sense. They are likewise able to communicate these thought processes to others through modes such as verbal explanations, written explanations, numeric explanations, images, graphs, and manipulatives. Through these informal proofs or argumentations, they can explain why they arrived at particular answers and how their conclusions compare to those that are accepted in mathematical communities.

In all, the discipline of mathematics requires students to work with a highly articulated system of abstractions that are both generalizable and applicable to specific situations. Over time, mathematicians have developed representations, definitions, and procedures in relation to these abstractions. Although students can devise their own representations and generalizations as they build understandings of new concepts, mathematical proficiency also requires students to read and use established representations and procedures and to understand the relationships between them. Students can apply mathematical reasoning to many situations that impact their quality of life in large and small ways as people, as consumers, as professionals, and as citizens.

Teachers' Conceptions of Mathematics

Tracy, Grace, and Karl each articulated a vision of mathematics that aligned with national standards. Tracy had been hired at her middle school because she had extensive training and practice in inquiry-based mathematics using a curriculum that she described as "basically an approach where students problem solve," which she contrasted to traditional textbooks whose approach was, "Here's how you do this problem, and monkey see, monkey do." Although Tracy used materials from this published curriculum, she just as frequently created her own materials that resonated with her philosophy of mathematics, which she described in the following terms:

> Mathematics is not five times seven equals 35. Mathematics is getting the student to actually have a problem that they can problem solve and think critically about. Math isn't about a bunch of equations and a bunch of algorithms that you have to learn. It's about being able to problem solve in everything, not just with numbers. Here's a situation, how do you meet it? I think that's really important, so to me, math is not just about answering problems; it's about really being able to apply those problem solving skills that you learned….I would rather have the student develop their own algorithm or rule for how to do something than pay attention to mine. Now that's not to say that I don't ever do examples with students and show them how to break things down, but as much as possible I try to get them to investigate on their own and arrive at their own conclusion because it strengthens their problem solving skills, and it makes them good mathematical thinkers.

Tracy often sought to develop students' "problem solving skills" through presenting them with challenging scenarios that they debated in groups as they developed responses that required them to use targeted mathematical concepts.

Grace, too, described problem solving as being at the heart of mathematics. When asked what she wanted her students to come away with in this discipline, she responded:

> First of all, I want the kids to be able to think, to be able to look at a situation, evaluate it, how can I solve this problem? Second thing is I want them to have functional skills that will take them into life, because you know, honestly a lot of our kids, once they get out of high school, they're never going to touch algebra again. But if they can do algebra, they've learned patterns, learned ways of looking at patterns and going okay, how can I analyze this pattern? How can I make sense of it?

Grace described her favorite mathematics teacher as one who eschewed what Tracy called the "monkey see, monkey do" approach to mathematics. Instead, Grace's favorite mathematics teacher "proved everything that we did, like this works because of this…She had her unit circle that she went through and explained why it worked, and once she had explained it—and she didn't just say, memorize this—I was like, oh okay, that makes sense. And you could figure everything else once you knew one thing." Grace adopted this approach to her own classroom as she sought to foster mathematical reasoning skills rather than asking them to simply "memorize this." She also sought to show them how if they knew "one thing," they could apply that principle to many different situations.

When asked what he wanted his students to come away with in mathematics, Karl similarly stated:

> I've always said this to students. They always ask, "Why is math important?" I say, "You need to learn how to problem solve." That's my biggest thing, problem solving. I always tell them, "No matter what job you have, the better you can problem solve, the more advanced or the further along you're going to get. You can't do that without math

> skills." When we solve an equation, they'll go, "Where are we going to use this?" The majority of them won't use it in their everyday lives, but the skills that they're learning, they're learning how to solve problems. They're learning how to take it step by step and break things down. I think that's—I try to tell them, "Okay, you may not use this exact thing, but the skills you're learning." So I'd say problem solving.

As part of his instruction on problem solving, Karl sought to emphasize that students can be flexible about taking different approaches to the same problem. "I think it's important that they understand that there are different ways of doing things," he explained. "I talk about, as you travel, you need to have different ways of getting to a certain spot. If one road is closed, you need to know another road. I think I try to bring that into the math as well."

Taken as a whole, the three teachers articulated *problem solving* as the core of their mathematics instruction, collectively seeking to develop students' reasoning in this area by teaching them there are multiple solutions to any given problem, to apply the same mathematical concept to multiple situations, to break problems into smaller steps, to recognize patterns, and to make and test generalizations. The teachers' daily essential questions likewise indicated their emphasis on problem solving: 77% of the questions required students to actively manipulate representations in search of answers to mathematical problems (see Figure 4.1).

Only 18% percent of essential questions required students to articulate conceptual understandings—such as the question *What is a ratio?*, whereas most of the other questions required students to apply their knowledge in search of solutions, such as using ratios in proportional reasoning to answer the questions *How do I use proportions to solve problems?* and *How do I use proportions with scales?* As these essential questions indicate, the three teachers instantiated mathematics as a discipline of action, one characterized by daily "dynamic operations and transformations, rather than…static objects or states" (Lesh, Cramer, Doerr, Post, & Zawojewski, 2003).

Texts in Mathematics

Mathematics teachers regularly integrated a variety of sign systems to support their students in this type of mathematical activity. Mathematics is often equated with the manipulation of numbers, but the three teachers in this study used numbers and symbols for only 23% of total representations, while written words comprised 29% of total representations and other texts such as images and gestures also featured prominently into their instruction. The descriptions below will illustrate how different modes were used to instantiate mathematics, while speculating on the relative affordances of each.

Numbers and Symbols

To many, numbers and symbols are the trademark sign system of mathematics. O'Halloran (2005) argued that for most professionals within the discipline, this mode is the *sine qua non* of their work because it is the primary means through which problems are solved. Its syntax enables quick "pattern matching" (Rumelhart, Smolensky, McClelland, & Hinton, 1986)—for example, through the alignment of numbers with the same place value in a problem requiring the subtraction of decimals. In this way, Wertsch (1998) asserted, numbers' "syntax is doing some of the thinking involved" and is "an essential part of a cultural tool without which we cannot solve this [subtraction] problem" (p. 29). Although visual arrays such as line graphs or shapes can also be essential to certain types of mathematical reasoning, they lack specificity and precision if they are not accompanied by numbers. Lemke (2003) described this affordance of numbers in terms of their ability to express topological meanings, or "meaning by degree," as compared to typological meanings, or "meanings by kind," best expressed by words.

In writing of the application of numbers and symbols and numbers to different problems, Giaquinto (2007) maintained that concept-driven symbol manipulation—including relocation, copying, deletion, substitution, and insertion—is preferable to rule-driven symbol manipulation. For instance, simply *copying* a formula, *substituting* numbers for letters, and *recopying* the formula on the next line while further *substituting* numbers (e.g., 24 for 8•3) does not necessarily promote or indicate meaningful mathematical reasoning unless this act is driven by conceptual understandings of what each component of the formula represents, how it was obtained, and/or when and why one might use it.

Just as the manipulation of numbers and symbols is central to the work of professional mathematicians, so, too, were numbers and symbols central to the work of the three teachers and their students, appearing in 82% of instructional episodes (see Table 3). At the same time, in 11 of 14 interviews about mathematics lessons, teachers ranked other modes as being more central than numbers in helping students reach their instructional objectives, in some cases ranking numeric and symbolic combinations last in importance. As part of their commitment to developing concept-driven symbol manipulation, teachers valued other modes as a means to helping students understand the reasoning behind why, when, and how they might use particular combinations and forms of numbers and symbols.

An example will indicate a lesson in which Tracy sought to develop students' concept-driven symbol manipulation as they learned how to numerically divide fractions. Tracy began her lesson by posting the following word problem on the board: "Naylah plans to make small cheese pizzas to sell at a school fundraiser. She has nine bars of cheese. How many pizzas can she make if each pizza needs the given amount of cheese?" Tracy initially wrote ½ under the word problem and said, "Let's pretend that Mrs. Smith [the school's home economics teacher] gives Naylah a recipe, and she says, okay, if you're going to make these cheese pizzas, you're going to need half a bar of cheese per pizza. How many pizzas can she make? So I want everybody to draw that on their board. Let's draw some cheese."

Working with an individual whiteboard, each student drew nine rectangles divided in halves, discussed their answers in groups, and told Tracy that they could make 18 pizzas total. "I saw some really interesting pictures," Tracy said.

> I was really interested in that back group over there. I said, well how would you write this problem? And Courtney said she felt like this would be nine times two [Tracy writes 9×2 on the front whiteboard], and then Kaitlyn said she thought it would be nine divided by one half. [Tracy writes $9 \times \frac{1}{2}$ underneath 9×2]. Let's think about that. Let's try that problem in another way. Instead of a half of a bar of cheese, the recipe says you need one third of a bar of cheese. Now let's figure out how many pizzas you can make.

Drawing nine similar rectangles to the ones they drew before, students partitioned the bars of cheese in thirds this time. Tracy again asked them to explain what they just did.

> *Student:* We took nine divided by one third.
>
> *Tracy:* Would it make sense for it to be nine divided by one third? Think about what that problem means. Nine divided by one third. What is that asking you to do? What is that literally saying?
>
> *Student:* Like take one third out of nine.
>
> *Tracy:* If you have the problem 36 divided by 2, what are you really asking here? [Tracy writes 36 ÷ 2 on a small whiteboard; see Figure 4.2].
>
> *Student:* How many times 2 will go into 36?

Tracy: Do you agree with that? [Students shakes heads yes.] So let's write that down [Tracy writes *How many times will 2 go into 36?* on the board.] How many times will two go into 36? So if I have a problem, nine divided by one third [writes $9 \div \frac{1}{3}$ on the board], what am I saying I want to do here?

Student: How many times one third will go into nine. [Tracy writes *How many times 1/3 will go into 9* on her whiteboard.]

Tracy: Does that make sense? In this problem, are we trying to figure out how many times one third will go into nine. How many times will one third fit into one bar of cheese?

Student: Three times.

Tracy: How many times will one third fit into nine bars of cheese?

Student: 27 times.

Tracy: How many pizzas can we make?

Student: 27.

Tracy: Again, we had a conversation at the other group, were we multiplying nine times three, or were we dividing nine by one third? What are we doing?

Student: Both.

Tracy: We're doing both? Both! That doesn't make any sense. What do you guys think back there?

As students continued the discussion and repeated the process for nine divided by one fifth, Tracy wrote the number pattern from Figure 4.3 on the board and then asked students what would happen if each pizza required 2/3 bar of cheese. This time, students debated whether the answer was $13\frac{1}{3}$ or $13\frac{1}{2}$, and Tracy asked two students to draw their answers on the board to model and explain their answers (see Figure 4.4):

Student: I drew nine lines. [Student drew nine lines on the board.]

Tracy: And what were his nine lines representing?

Student: Cheese.

Student: Then I took them and wrote lines [divides each line into thirds]. And then this would be 1, 2, 3, 4, 5, 6, 7, 8, 9 [points to top nine groups of two thirds].

Tracy: Can you circle for me what you're talking about? [Student circles top nine groups of two thirds.]

Student: This would be nine pizzas [points to circled group], and then you add these four [draws swoops under four groups of two thirds and numbers them *10, 11, 12, 13*], and then there's one right there [points to remaining piece]. Thirteen and one third.

Student: Thirteen and one half.

Tracy: Can we talk about that in our groups? Some of us are saying thirteen and a half pizzas, and some of us are saying thirteen and one third.

Tracy: Derrick is going to talk to us a little bit to explain what his answer is going to be.

Student: Okay, it's not asking how many pieces there are. It would be two thirds to make one pizza. We have one third left, and that can make a half a pizza.

Student: Oh, okay.

Tracy: Can you give your explanation of why you think you're right? [Tracy points to another student.]

Student: It's asking how many pizzas you can make with two thirds. Two thirds make *a* pizza. So if you have one third left, you can make half a pizza.

Student: They were thinking of how many pizzas they could make, but we were thinking of what part of the cheese we have left.

Tracy: Is there a difference between how many pieces of cheese you have left and how much pizza you can make?

Student: We were thinking it couldn't be thirteen and one half. They were thinking it's one half of cheese for a pizza, and we were thinking, no it couldn't be one half because this is what it would look like if was thirteen and one half [uses thumb and index finger to point out one half of a bar of cheese on his whiteboard].

Tracy: Do you want to talk a little about what Jorge was thinking?

Student: Well if it takes two thirds to make *one* pizza, then you have one third left, and then so you just need another third to make another pizza.

Tracy: Now we do have a third of a bar of cheese left, and a third of a bar of cheese will make what?

Student: A half of pizza.

Tracy: I don't get what we would multiply by. Could we write this as a multiplication problem? How?

Using the patterns that had been established in the previous division problems, Tracy's students continued to alternate between small-group and whole-class discussion to establish that, in order to divide fractions, you had to "switch the second number," to use one student's terms, and multiply it by the first. This lesson ended with the generation of what Tracy called a "number sentence"-- $\frac{9}{1} \times \frac{3}{2} = \frac{27}{2} = 13\frac{1}{2}$ --after students had devised an algorithm for dividing fractions based on the numeric patterns they noticed, based on images they had drawn, and based on the debates they had held.

In a rule-driven lesson on division of fractions, a simple act of symbol manipulation would have been required to change a numeric exercise ($9 \div \frac{2}{3}$) to a numeric answer as students changed the multiplication sign to a division sign and "switched" the second fraction. However, Tracy believed that a concept-driven approach to symbol manipulation required a word problem to "put the problem in context," as well as visual representations and discussion to develop conceptual understandings. She maintained that the images reinforced concepts of division by helping students to perceptually see that "I've got nine bars of cheese; I'm trying to see how many times two thirds is going into it." She ranked the final number sentence as less important to developing in-depth understandings than the images and word problem in this case because it was "just sort of the summary…[but] I think getting that picture and getting that verbal communication is the most important thing" in this case to prevent the division of fractions from becoming "memorize a bunch of rules and use those rules."

At the end of the year, Tracy explained why she used numbers and symbols more frequently than any other type of representation: "I really do look at math as being a completely different language for kids to be able to communicate with, so I think that's it's kind of important to be able to see the numbers and symbols as you're talking about them and as you're using them. Whereas with science, even though you have a lot of new vocabulary, it's not a completely and entirely different language, and math is a whole new way of communicating." At the same time, although numbers and symbols were the defining mode of this "completely different language," learning the single sentence $\frac{9}{1} \times \frac{3}{2} = \frac{27}{2} = 13\frac{1}{2}$ required the mediation of many other forms of representation: a word problem, images, verbal discussion, written words on the small board, and numeric symbolic solutions from easier problems. In future lessons, Tracy and her students discussed the benefits of using numbers and symbols rather than images, concluding that images could be difficult to partition precisely depending on the fraction and that numbers were more time efficient. In this way, the obvious affordance of numbers and symbols is that they often most precisely and quickly enable the actual *execution* phase of problem solving in which a solution is actually calculated (Mayer, 1989). However, Tracy valued other modes, such as images whose form bore some type of perceptual similarity to an object in the world (cheese), as central to the process of learning this mode.

In this example, students learned how numbers and symbols could be used to represent a particular activity (e.g., taking groups of two thirds from nine wholes) and how they connected to other representations of the same activity. Another important purpose of symbol manipulation entailed choosing the best type of number for the job at hand, at times changing the same number to another form of that number. Prior to Tracy's lesson, her students had already learned about how to change a mixed number (e.g., $13\frac{1}{2}$) to an improper fraction ($\frac{27}{2}$), and vice versa, the latter of which is a useful representation for operations such as multiplication and division of fractions. Even this one act of translation between numbers required intensive instruction that was mediated by the use of images.

The act of translating between written numerals becomes further compounded when one considers that $4\frac{3}{4}$ can also be represented as 4.75 (among other ways) and that one might select a particular numeric representation, not only based on whether that number's spatial arrangement enables one to perform a particular operation, but also based on whether that number would be appropriate and useful in a particular context. Grace tried to foster this type of conceptual understanding when she asked her students to translate between fractions, decimals, and percents, beginning her series of lessons by asking students to brainstorm what they knew about each one and to make comparisons across them.

She then gave her students a word problem, which the students acted out by mimicking a basketball game through dribbling and shooting imaginary balls:

Word Problem: The Portland Tigers are playing the Coldwater Colts in basketball. The game is tied 58 to 58, but in the excitement both coaches step onto the court just as the buzzer sounds. A referee calls a technical foul on each coach. Each coach has to choose on player to make the free-throw attempt. Which player should the Coldwater Colts and Portland Tigers choose to make the free throw attempt? Explain your reasoning.

Grace: [reading the statistics on Coldwater Colts] Angela made 12 out of 15 free throws; Emily made 15 out of 20 free throws; Christina made 13 out of 16 free throws. Who's the best free throw shooter here?

Student: Christina.

Grace: Why do you think Christina is the best free throw shooter?

Student: Because I thought that she missed three. And Emily, she struck fifteen out of twenty, she missed five.

Grace: You want Christina who missed three over Angela who missed three? But Angela and Christina missed the same number. They both missed three. What do you think, Roberto?

Student: Emily.

Grace: Why do you think Emily?

Student: Because she made more shots.

Grace: Because Emily got the most? Okay.

Student: I think I would pick Angela because she might have tried the least amount but she got, um, [silence].

Grace: It's kind of hard to explain isn't it?

Student: I think Emily because even though she missed the most she got fifteen shots though, that's still more than anyone else. And she got all sweaty and stuff and she was tired by the end.

Grace: It's kind of hard to pick who would be the absolute best free throw shooter. Is there any other way we could look at it? Besides looking at the actual number they got and the actual number they missed?

Student: Look at the number they tried.

Grace: So if I only tried three shots, but I made three out of three, I might be the best free throw shooter. Can I write these as fractions? Go ahead and write the fractions you would put for each of those girls. Now that we've got them written as fractions, can you tell who is the best free throw shooter?....Let me ask you this. If they all made 20 shots, if they all shot the ball 20 times [pretends to shoot basketball], if they all attempted 20 times, would you be able to tell then who was the best free throw shooter? If they all had done 20, how would you know who was the best free throw shooter?

Student: Who had the most shots.

As students discussed whether there were any way to establish a common denominator for the three shooters, Grace introduced the visual from Figure 4.5 to show how fractions compare to percents, and students used this image to convert fractions such as $\frac{15}{20}$ to $\frac{75}{100}$ and then to 75%. Students noted how percents would be more useful for helping them pinpoint the best free throw shooter because percents established a common basis for comparison (per 100). After one student asked how to convert a fraction to a percent if you had a denominator such as 30 that did not go evenly into 100, Grace responded, "Let's make it something like seventeen out of thirty [writes $\frac{17}{30}$ on the board]. Think about what this line means [points to line between numerator and denominator]; what does it mean to do?"

Students then realized that they could transform a fraction to a percent through division after first changing the fraction to a decimal. To give them further practice with these translations between the same numbers, Grace asked her students to play the "penny game" in which they each had a handful of pennies that they shot into a plastic cup and then converted their fractions to decimals and to percents in order to decide who they would want to make free throw shots in a high stakes situation.

Like Tracy, Grace ranked the visual image, the word problem, and the discussion surrounding these representations as being more useful in developing conceptual understandings than the actual numeric translations between fractions, decimals, and percents. Grace asserted of the latter, "I just think computation is boring. You could sit there and do computation all day long. There's no thinking. It's just rote, doing something over and over again." In contrast, she argued the other representations more fully helped students to think about when and why they might use fractions or percents and how they related to one another.

In all, just as numbers and symbols are a privileged mode among professional mathematicians, so, too, were they a focal mode across the three middle school mathematics classrooms as suggested by the frequency count. However, to promote the concept-driven manipulation of numbers and symbols, the teachers viewed other modes as essential in building understandings of this mode: whether it was drawings of cheese in Tracy's class, or an image of 100 boxes in Grace's class—the three teachers ranked these modes as more essential to building conceptual understandings than the direct manipulation of numbers. As teachers employed multiple modes to teach abstractions of *division, fractions, percents,* and other concepts, students learned how numbers could represent different types of activity, why and when they might select particular numeric "material avatars" to meet the demands of particular situations, and how numbers correlated with other representations, such as graphs or images. In this way, as students initially learned about different types of mathematical activity, numbers and symbols were viewed as being more meaningful and useful only when they appeared in conjunction with other modes.

Instructions and Word Problems

Connolly and Vilardi (1989) asserted written and spoken language provide the metadiscourse for other sign systems in mathematics, enabling students to describe numbers, symbols, graphs, and other representations through this medium with which they are comparatively familiar. Koedinger, Alibal, and Nathan (2008) similarly describe one function of written language as providing a "grounded representation" in the sense that "grounded representations, such as verbal descriptions of situations, are more concrete and familiar [than numbers and symbols], and they are more similar to physical objects and everyday experience" (p. 266).

Framed in this "concrete and familiar" mode, word problems were a common genre in mathematics. Grace described them as "one of the most important [texts in mathematics] because what's the point in being able to do computation if you can't use it?....The word problem is not necessarily *how do I* but it's *when do I,* which is a more practical application for the real world." Like Koedinger, Alibal, and Nathan, she described the affordance of this mode as one that served the purpose of grounding mathematical activity in world experience. This potential of words to *contextualize* was a phrase echoed by Tracy and Karl and indeed by many other mathematics teachers (Reed, 1999). *Instructions,* the only genre of written words used more than word problems, contextualized mathematical activity in another way: They provided a metalanguage for approaching and solving problems. In Grace's words, "I think it's important for students to be able to explain the steps to me because if they can explain it, that shows me that they really do know it….If they can do that, there's a really good chance that they can solve the problems."

Gestures

In her synthesis of a collection of articles about gestures in mathematics, Sfard (2009) argued that gestures in this discipline are "invaluable means for ensuring that all the interlocutors 'speak about the same mathematical object.' (p. 197). The three teachers' use of *pointing,* comprising 63% of total gestures in their instruction (see Figure 4.6), confirmed this primary use of gestures. Karl, Grace, and Tracy pointed to specific angles, specific points on a graph, specific symbols, and specific parts of three-dimensional figures to accompany verbal discussions of them, individually and collectively using pointing in this discipline more frequently than in any other.

Several examples will demonstrate how pointing was essential to mathematical communication. In one instructional episode, Karl's students were trying to answer a multiple choice question requiring them to prove that a triangle with given coordinates was a right triangle. Karl drew a right triangle with the specified coordinates on the board (see Figure 4.7) and continued:

> If I have my right angle here [draws a box around the right angle of the triangle and points to it], I have two sides that have something in common [points to the lines along the x and y axis connected by the box], and I have this third side [points to the side of the triangle that is diagonal from the box]. What do you think this third side is called?
>
> *Student*: The hypotenuse.

Karl: The hypotenuse. What do we call the other two?

Student: Legs.

Karl: If I go down here [points to multiple choice question], legs and hypotenuse, which of the ones are going to help us prove that this [points to the two lines on the triangle along the x and y axis] is perpendicular?

The exchange continued as Karl pointed between the answers on the multiple choice question, the Pythagorean equation at the top of the board, and the two triangles to elicit discussion on how specific components of the equation would relate to specific parts of the triangles, which in turn would relate to specific answers on the multiple choice question.

As another example of this type of gesture, Grace pointed to sides of a cracker box and to rectangles on a flat drawing (see Figure 4.8) to show how each side of the box correlated with a specific rectangle, how each rectangle on the flat drawing correlated with a specific number on the right indicating its surface area, and how each number on the right correlated with a specific part of the formula for surface area of a rectangular prism. In a lesson on converting units in the metric system, Tracy similarly pointed to specific numbers and asked students, "What place is right here? What place is this?" as students identified that moving a decimal one place to the right or to the left would indicate multiplication or division by ten, necessitating the use of a larger or smaller unit (e.g., centimeters to millimeters).

These and many other examples indicate the prevalence of pointing in mathematics as "an inherently interstitial action, something that exists precisely at the place where a heterogeneous array of different kinds of sign vehicles…are being juxtaposed to each other to create a coherent package of meaning and action" (Goodwin, 2003, p. 238). Ifrah (2001) and

O'Halloran's (2009) histories of mathematical symbolism begin to offer possible explanations for why this type of gestural interstice is especially important in mathematics.

They argued that mathematical notations developed largely as a written modality, unlike written words that first developed as oral speech. Even when people historically used abacuses or tokens to solve mathematical problems, one affordance of visible or tactile representations in mathematics is that they enable people to calculate solutions. When one is working with large numbers or complex multi-step problems, for example, it is difficult for many people to use verbal speech or "mental math" to make precise computations, but tools such as written numbers have historically made it easier to perform algorithms by physically manipulating these material avatars. In other words, what can be done with numbers and manipulatives in mathematics perhaps cannot be done (or least done as accurately) with verbal speech.

In mathematics, then, pointing served as a key mediator between verbal explanations and the visual/tactile representations (such as written numerals) that enabled actual computations. Moreover, pointing also served as a mediator between different visible material avatars of the same concept, such as Grace's example of using pointing to show how one rectangle on a drawing, one side of a three-dimensional figure, one written numeral, and one part of a formula all "stood for" the same abstraction: the surface area of one side on a rectangular prism.

Mathematics' emphasis on precision necessitated pointing as well. In a discipline where the movement of a "dot" one millimeter upward or downward can make the difference between whether it symbolizes a decimal or multiplication sign, or where the movement of the same "dot" over one place value can indicate multiplication or division by ten, it was necessary for teachers and students to communicate absolute precision in putting *this* symbol here in *this* exact place.

Although non-pointing gestures proved useful in illustrating particular concepts such as *shape*, in all cases teachers ranked these gestures as among the least useful types of representation in terms of helping students reach their instructional objectives. Other modes such as images and numbers, in contrast to gestures, leave a record that can be manipulated, annotated, and examined. Although gestures could indicate shape, they did not do so with the same exactness or permanence as an actual object or drawn image. In this way, non-pointing gestures seemed to lack the precision required of mathematical discourse, a precision more fully communicated by pointing gestures coupled with other representations.

Images

Images comprised 13% of total representations across the mathematics curricula, including geometric shapes (n=41), drawings (n=19)—and, to a lesser extent—photographs (n=3), maps, (n =2), and moving images (n=2). With the exception of the photographs and the moving images, images were used for at least one of two purposes: (a) to mediate students' thinking in arriving at solutions to problems; and/or (b) to compare and contrast the properties of angles and geometric shapes. Although images were used half as often as numbers and symbols, teachers more frequently ranked them as being more important to helping students reach their instructional objectives. A few examples will show how teachers and students used images to solve problems and to explore the properties of geometric shapes.

In a lesson on dividing fractions, Tracy showed worked with a small group of students, each of whom had their own whiteboards and a paper with the image from Figure 4.9. To begin solving a word problem in which a group of families owned one section of land, Tracy said, "Our job is going to be to figure out how much of a section each person owns. Looking at Section 18, how many people are in that section?"

Student: Eight.

Tracy: So that means each person has one eighths of a section.

Student: No.

Tracy: Why not? Why wouldn't each person have one eighth of a section?

Student: They're not all equal.

Tracy: What are not equal?

Student: The sections.

Tracy: When we cut something into eighths, we're saying there are eight equal pieces. But there are not eight equal pieces in this section….Who do you think would probably be the easiest to figure out?

Student: Lapp.

Tracy: Does everybody else agree? [Students nod heads yes.] Let's look at Lapp's section. Check out Lapp's section. I want you to write down what fraction of the land you think he might have. And we're talking about just what fraction of that section, Section 18. [Students hold up whiteboards with different answers.] So let's look at Lapp's section again and look and see what would be the best answer again. Lapp, he's sort of up there in that corner. We have one person who says one fourth and one person who says one eighth.

Student: If you imagine a line right here and right there [points to two lines he had drawn that extended the horizontal and vertical lines from the Lapp section out to the edge of the section boundaries], it would be equal to four.

Tracy: I like what Devin did. He kind of extended his line a little bit to show what the sections would look like. I see that Annie has written out two eighths. Who wants to talk about that?

Student: It's pretty much the same thing.

Tracy: Pretty much the same thing as what?

Student: One fourth.

Student: It's simplified.

As the instructional episode continued, the rest of the students borrowed Devin's strategy of drawing lines on the map to figure out the sizes of the remaining sections. They noted similarities among sections, such as the fact that Fuentes and Bouck seemingly owned the same amount of land, whereas Krebs owned half of what Fuentes and Bouck owned. Using the visual patterns in the image and what they knew about relationships between fractions, students figured out what fraction of the land was held by each person.

Karl similarly used images as a means to teach problem solving in mathematics. In one lesson, students sought to solve the word problem: "Ben and Carl were in a 100-meter race. When Ben crossed the finish line, Carl was only at the 90-meter mark. Ben suggested they run another 100-meter race. This time, Ben would start ten meters behind the starting line. All other things being equal, will Carl win, lose, or will it be a tie in the second race? Be ready to explain your answer." Most students indicated through a whole-class vote that they thought the answer would be a tie because Ben won by a distance of ten, and during the second race, he would start behind Carl by that same distance.

In response to their explanation, Karl drew an orange line on the board labeling the start with an *S* and the finish with an *F* (See Figure 4.10). "Remember the first time," he continued.

> When Ben was here [points to finish line and labels it *B*], Carl was here [draws a black line behind the finish line and labels it *C, 90 m*], 10 meters behind him [writes *10 m* with an arrow from B to C to indicate that Ben won Carl by 10 meters.] So in the same time Ben can run 100 meters, Carl can run 90 meters.

Karl then drew a line behind the starting line indicating the point at which Ben would start the second race (10 meters behind Carl) and asked students where Ben would be when Carl was at 90 meters of the second race. Students identified that Carl and Ben would be at the same point at the 90-meter mark of the second race because Ben could run 100 meters in the same time that Carl ran 90. They subsequently concluded that Ben would win the second race as well because after that 90-meter mark, Ben would run faster than Carl. Karl represented this explanation visually on the board through drawing two black lines under the initial orange line. The first black line represented Carl; the second black line represented Ben; and the vertical line representing 90 meters indicated the point at which they would be tied in the second race. This word problem was then used to begin a discussion of rate.

The previous two examples indicated images' use in solving problems, but a final example will indicate a second use of images: to identify patterns in angle relationships or geometric shapes. After Tracy's students traced "nets" and used them to construct solid figures, Tracy reviewed the relationship between the flat nets and the three-dimensional figures. Holding up a potential net for a cylinder (see Figure 4.11), she asked students what solid figure the net would make.

> *Student:* A cylinder.
>
> *Tracy:* How on earth did she know this was a cylinder? This net [holds up cylinder one] does not look like the net that came with the cylinder [holds up the blue plastic net that students had previously folded into a cylinder]. Here's this net [holds up cylinder one]. Here's this net [holds up blue plastic net]. You guys are still telling me this [holds up cylinder one] is a cylinder. Why?

Student: Because if you don't roll it on the right, but you roll it on the left, the circles will still match up.

Tracy: No matter how we roll it, we still have the same shape. Which is what?

Student: The faces will be circles.

Tracy: We only have one surface to serve as our face [traces rectangle with finger]…Would this one [holds up cylinder three] work for a cylinder as well? So what do you notice about all three of the nets that we have for our cylinder? What do they all have in common? Here's one, two, and three [holds up each cylinder]. Why do we still think that all of these would work?

Student: They all have two circles and a line.

Tracy: They all have two circles, and what shape is this [points to rectangle]?

Student: A rectangle in the middle.

Tracy: So what if my net looked like that [traces fourth net on the board]. What do you think, guys? Would that one work? Give me a thumbs up or a thumbs down. [Students give her a thumbs down.] Why do we think it would not work?

Student: It doesn't have a circle on top and bottom.

Tracy: It doesn't have a circle on the top and the bottom. So the circle is supposed to be our--

Student: Base.

As indicated by these examples and those described previously, images in mathematics could be used to represent many different things: bars of cheese, an aerial view of plots of land, a race, free throws, cylinders, and more. Despite different referents, however, images across the mathematics teachers' curricula tended to share one common attribute: The drawings were minimal and eliminated details except those necessary to solve the problem and/or recognize a targeted pattern. Thus, a bar of cheese was represented by a green line; a plot of land was represented as a white rectangle; a race between two people was represented as a series of lines with arrows and labels, and so forth. The teachers did not ground these examples in photographs of cheese, maps with fences that formed curved or crooked boundaries, a video of two runners competing in a 100-meter dash, or flower pistons and oatmeal cartons that might serve as "real life" cylinders. In this sense, images in mathematics were usually not constructed according to their ability to resemble what students would see upon observing a physical referent from their everyday lives.

O'Halloran's (2005) description of the historical development of mathematical images offers possible reasons for this abstraction of images. She argued that published mathematical images were often grounded in specific physical situations, such an image of a man firing a cannonball, prior to the seventeenth century. Over time, mathematicians moved toward "present[ing] the terms of the difficulty so plain and unencumbered that, while omitting nothing which is needed, there is also nothing superfluous, nothing which engages our mental powers to no purpose" (Descartes, 1952, p. 101). As part of this move toward abstraction, many mathematical images came to eliminate details that would ground them in specific physical locations. Later images projecting a cannon ball's trajectory, for example, were set apart as a series of lines and curves in blank space.

Echoing O'Halloran, Boyer (1985) similarly argued that "thousands of years [were] required for [humans] to separate out the abstract concepts from repeated concrete situations…It was only in the nineteenth century that pure mathematics freed itself from limitations suggested by observations of nature" (p. 1, 5). In the same way that numeric/symbolic combinations grew to "free" themselves from specific situations (e.g., the avatar "*10"* could represent *10* degrees

Fahrenheit, *10* cows, *10* cents, or simply *10*), mathematical images likewise followed a developmental arc toward “freeing” themselves from idiosyncrasies and particularities observable in the natural world.

The absence of photographs and video footage indicated that images also moved toward abstraction and generalization by representing mathematical concepts in idealistic forms that did not exactly cohere with students’ everyday perceptual realities. These abstract visual representations, such as Grace’s image showing the relationship between fractions to percents, afforded students with the ability to apply the same visual representation to many different specific circumstances besides just free throws.

In all, images worked with other modes—in these cases, written word problems, pointing, verbal discussions, and numeric and symbolic combinations—to help students reason about problems and recognize patterns across shapes and mathematical concepts. Teachers believed this mode was an indispensable component of students’ learning in this discipline. Though images at times physically resembled an observable referent to a greater or lesser extent, they concurrently represented abstract mathematical concepts such as rate, operations with fractions, and conversions between fractions and percents. This dual role grounded many mathematical images in both the world of students’ everyday perceptions and in the realm of abstraction, serving as a bridge between the two.

Manipulatives and Objects

Like images, manipulatives and objects served as visuals intended to build students’ conceptual understandings about mathematical operations. Tracy’s students, for example, used fraction blocks (see Figure 4.12), with each color representing a whole cut into a different number of pieces, to review how to add and subtract fractions. Students solved several problems using the fraction blocks, such as when Tracy asked a small group to “Please show me two thirds,” to which students responded by placing two blue thirds on their individual small whiteboards. Tracy continued: “We want to take away one half. This is one half [holds up a red block], isn’t it? Everybody take your half. If you look at the half there, now can I take that one half away? …What can I do so I can take away this much [holds up red block representing one half] from the blue?”

The group of students responded to this prompt through discussing various strategies for solving this problem with the manipulatives, ultimately deciding to overlay four green pieces (each representing one sixth) over the two blue pieces (each representing one third) to prove that four sixths equaled two thirds. They also overlaid three green pieces on one red piece (representing one half) to prove that three sixths equaled one half. They then used this information to subtract three green pieces from four green pieces, or three sixths from four sixths, asserting that it was the same as subtracting one half from two thirds as the original instructions had specified.

Grace also used manipulatives to teach addition and subtraction of integers. She began by asking students, “Have you ever heard any adults saying, *I am in the red?* What does it mean to be in the red?” Students identified that it meant “you owe money,” generated a few examples in which people might owe more money than they had, and brainstormed other instances in which one might use a negative number such as yards lost in a football game or negative degrees Fahrenheit. Grace then gave each student a pile of red and yellow tiles, each of which represented a negative one or a positive one.

Grace: Remember, yellow is sunny, bright, and positive. It's a good thing….Say I have seven dollars in my wallet, but I spent four dollars, and I had three left. Pair up a red and a yellow. Every time I partner up a red and a yellow, what does that equal?

Student: Zero.

Grace: [Writes $7 + -4 = 3$ on the board.] Right. You have a dollar, you spend a dollar, how many dollars do you have left? Zero. I have seven positives, and I partner it up with four negatives. [Puts seven yellow circles on the board and places four red circles under four yellow circles.]

Grace: What I want you to model right now is negative five plus three [writes -5 + 3 on the board]. Model that. Who wants to come up here and model negative five and three? [A student comes to the Smartboard and places three yellow circles underneath five red circles].

Grace: And what did you get for your answer?

Student: Negative two.

Grace's students continued their discussion of integers by using a number line to add positive and negative integers as well as by playing a whole-class game that required the addition of positive and negative points.

As these examples suggest, manipulatives' affordances relate to their ability to perform as interactive mediums that enable their users to experience change perceptually, actually witnessing transformations, unlike symbols wherein signs such as + and – signify change without leaving perceptual traces of the actions behind them (cf. Brenner et al., 1997; Goldin & Kaput, 1996). In a discipline wherein mathematical activity is a goal of teachers' instruction, yet numbers perceptually hide this activity, the teachers expressed this mode as being among their most important when it was used in 14% of instructional episodes.

Reading Practices Specific to Mathematics

These descriptions of the most common texts used across the three teachers' instruction would suggest that, when notions of "reading" are expanded to incorporate students' sense-making of multiple sign systems, this discipline required students to comprehend and use a variety of images, manipulatives, and numbers and symbols. Many instances of written words—such as instructions and word problems—often served to facilitate, prompt, direct, contextualize, or explain the manipulation of these visual and symbolic representations as gestures often drew students' attention toward specific aspects of them. When the term "reading" encompasses these modes, several practices become important and distinctive to the reading of texts in this discipline, including: (a) the unique nature of verbal transmediation from written numerals to speech; (b) the specific reading paths required by numbers and symbols; and (c) the reading of various markers that "point things out."

Verbal Transmediation of Written Numerals

In one sense, students' oral reading in any discipline may somewhat indicate their understanding of what they are reading. For example, a student who reads a play with great emotional inflection in English may show that he understands something about the psychological state of a given character, or a student who verbally stumbles over many words in a science or history textbook may indicate she is having difficulties with engaging in its ideas. Nonetheless, the act of verbally reading numbers and symbols aloud is perhaps unique in its ability to provide insight into how students understand them because there is not a direct correlation between numbers and spoken words as there is between written words and spoken words.

For example, Grace and Tracy repeatedly reminded their students to read numerals such as 5.4 as *five and four tenths* rather than *five point four,* a practice that they themselves modeled when reading numbers aloud to their students. When reading the ratio 1:4 and $\frac{1}{4}$, Grace reminded her students, “You say the word *to.* So I don’t say wins divided by losses, or wins colon losses, or wins over losses, I say wins *to* losses.” After a student read *one fourth,* Grace reminded him that a ratio did not represent a part to a whole like a fraction, but instead represented a comparison between two things.

As another example, one of Grace’s students read 15^3 as *fifteen with a three.* Grace then held the following exchange with this student:

> *Grace:* With a three? In place of a three?
>
> *Student:* Fifteen times three.
>
> *Grace*: With an exponent of three.
>
> *Student*: No.
>
> *Grace*: Times three [repeating his answer], okay, that’s your mistake. This (points to 15^3 on the board) means 15 cubed, or 15 times 15 times 15. This (writes 15•3 on the board) is 15 plus 15 plus 15.

As this example indicates, just as there are many different ways of accurately representing the concept behind a written number, there also are many different ways of verbally translating a number: 15^3 can be *fifteen times fifteen times fifteen, fifteen cubed,* or *fifteen with an exponent of three,* for example. Likewise, one can imagine reading $5\frac{1}{3}$ as five and a third; or five wholes plus one piece of something that has been divided into three equal pieces; or sixteen thirds; or multiply five by three and add one, then divide that answer by three; or even five point three three three etc., all readings of which would approximate the same abstraction behind the written numeral $5\frac{1}{3}$. In mathematics, then, students' verbal readings of numerals can provide insight into how they understand numbers, and students may require explicit instruction on how to translate written numbers into verbal speech as part of building their conceptual understandings about the numerals' meaning.

Specific reading paths. The reading of numeric and symbolic combinations is unique in another way as well: These combinations require specific reading paths that can vary depending on the operation being performed. Kress (2003) has argued that written words, unlike images, carve out a particular reading path for their users as people must read paragraphs from left to right and top to bottom in many Western languages in order to construct coherent meanings from the text. A written numeral, too, is generally read from left to right, especially when one is reading the numeral verbally. For example, in 1,102, the one in the thousands place is typically read before the two in the ones place.

A large part of the three teachers' instruction, however, entailed teaching students that a series of numbers and symbols could not simply be understood from left to right but instead required a reading path that was specific to the conventions of mathematics, one grounded in a firm understanding of the "grammar" of numerals such as their place values. Part of Grace and Tracy's instruction, for example, entailed teaching students the order of operations, which Grace introduced to students by asking them to evaluate the expression $21 - 3(10 - 7) + 6^2/12$. Every student in the classroom arrived at a different answer, ranging from 5 to 408, which Grace wrote on the board. She then told students that, in order to communicate their ideas in uniform ways that could be understood by others who read their work, mathematicians devised the order of operations to ensure that a group of people could understand a series of written operations in the same way. Although "left to right" orientation played a part in this reading path as students sought to calculate an answer, according to mathematical convention, they should have first attended to the numbers in parentheses that appeared in the middle of the expression. Likewise, students at times approached individual written numerals, such as *1,102*, from right to left when they performed algorithms for addition and subtraction by first attending to the ones place value in numbers.

Kress (2003) has argued that a defining characteristic of written language is its nature to unfold according to the logic of time, requiring the reader to encounter line by line and word by word in a temporal sequence, whereas images are governed according to the logic of space, revealing all of their components simultaneously. Numeric and symbolic combinations, perhaps, were written according to a different logic, one that relied on both space (e.g., numerals had to be spatially aligned in certain ways) and time (e.g., first you do this step, then you do this one), but in a way that was not as straightforward and unilateral as the path required for written words or as open as the paths enabled by images.

For instance, while students can acceptably begin to read an addition problem by addressing the last numbers first, without changing its meaning as part of the commutative property of addition (4+3 is the same as 3+4), they cannot do so in a subtraction problem. Consequently, when faced with a string of numbers and symbols whose meaning they had to comprehend, students often required specific instruction as to "where to start" reading, a question that might have multiple acceptable answers depending on the numeric and symbolic equation or expression and depending on the task that the student sought to accomplish.

Color. As the frequent use of pointing gestures suggested, *pointing something out* was a common feature of mathematics instruction as students and teachers used their fingers to ensure that all participants involved in acts of communication could distinguish *one* particular mathematical object (e.g., one point on a solid figure; one point on a coordinate plane) from others. Pointing with fingers was not the only way to set apart one concept from another, however. Teachers' use of color also frequently served to differentiate among mathematical ideas.

One word problem, for example, required students to use proportional reasoning as they compared the number of Jolly Ranchers to Sweet-Tarts in a candy basket. As part of the class's discussion of this word problem, Grace highlighted the words *Jolly Ranchers* and the number of Jolly Ranchers (*four*) in yellow, highlighted the word *Sweet-Tarts* and the number of Sweet-Tarts (*six*) in green, and finally highlighted the target number of Sweet-Tarts (*51*) in green. When asked, *If there are 51 Sweet-tarts, how many Jolly Ranchers are there in the basket?*, students wrote a variety of acceptable numeric equations similar to the ones in Figure 4.13. Grace hoped the colors in the word problem would help students differentiate and organize the information, regardless of the order in which they wrote their subsequent ratios.

As a second example of using color to "point things out" in mathematics, Karl's students solved pairs of inequalities (e.g., $y \leq x + 3$ and $y \leq x - 2$) by graphing one line for each inequality, shading the area under each line in a different color (e.g., blue under the first line and red under the second), and using a third color (e.g., purple) to shade the area wherein the solutions overlapped (see Figure 4.14). Similarly, when asked during an interview if she had anything additional she wanted to share, Tracy stated, "I also like to use a lot of different colors when I'm writing something on the board so that they can see what each thing is a part of." When asked "Do the colors stand for anything specific?" she replied, "No, just to separate out each piece…like one color didn't stand for anything in specific, but every time I moved to a different thing, I just used a different color."

Many previous examples also indicate color's ability to represent a "different thing" in this discipline: colored tiles to distinguish between positive and negative integers, colored fraction blocks to distinguish among different denominators, colored lines to separate the first race from the second race, colored tiles to represent between positive and negative integers and more. Just as *pointing* separated one thing from another, *color* provided a more permanent means of separating one thing from another. Unlike in earth science where color often mimicked that of an entity in the world, colors in mathematics did not often bear any relationship to a physical referent.

Kress and van Leeuwen's (2006) discussion of color begin to suggest reasons for why many mathematical representations were characterized by bright colors. They argued that bright mono-hued solid colors represent *low modality,* or low "truth value," signaling to viewers that objects with these colors do not exist in a naturalistic reality. For example, if a photograph's subjects were all an undifferentiated solid red, one might conclude that the photograph was "doctored" in the sense that its subjects did not exist in a natural setting wherein multi-hued, differentiated objects abound. According to Kress and van Leeuwen's logic, objects with monochromatic colors would also signal that "this" (tile, fraction piece) does not represent something that naturally exists. In this sense, the teachers' frequent use of bright solid colors (e.g., red and yellow tiles; blue fraction manipulatives) perhaps further instantiated mathematics as a discipline whose objects existed in an idealized realm of abstraction in some ways removed from students' everyday perceptions of reality.

Possibilities for Reading Instruction

The most common types of texts in mathematics—numbers, images, and so forth—instantiated mathematics as a discipline wherein the act of reading was often subsumed under larger activities of *solving problems* and *identifying patterns* (Devlin, 1994; Schoenfeld, 1992).

Other researchers (Draper, 2002; Fogelberg et al., 2008) have noted how comprehension strategies applied toward the reading of written texts can also be applied toward mathematical problem solving as students read numeric texts or word problems. Their recommendations include the following:

- *setting a purpose for reading* by deciding what you are going to solve for and how you plan to do it
- *predicting* or estimating what a problem's solution will be and *checking predictions* during and after generating solutions
- *predicting* or conjecturing about a pattern that might hold true across all numbers and *checking predictions* by looking for examples that do not fit the pattern
- *summarizing* the process by which the solution was arrived at the end
- *asking questions* about unclear material
- *determining relevant information* through annotating important parts of word problems
- *monitoring comprehension* by continually asking, "Does this make sense?"
- *making connections* to similar but easier problems
- *visualizing* by drawing images related to the problem
- *evaluating* the solution at the end.

While these strategies resonate with time-honored recommendations for teaching mathematical problem solving (e.g., Polya, 1945), they may nonetheless differ in mathematics in ways that are significant from other disciplines. This section will describe how visualizing, connecting, distinguishing salient information, and predicting in mathematical texts can differ in this discipline.

Visualizing

Visualizing across the content areas can take many different forms. A student in English might imagine a character's appearance and physical surroundings upon reading a story, for example, while an earth science student might envision what a landscape would look like after months of extensive rain after a field trip around the school campus. The mathematics teachers also used visual projections as a key tool to support students' understandings, but visualizing tended to take on a different form as illustrated by the following example of Tracy's instruction. Her lesson began as students worked in small groups to discuss and illustrate possible answers to the following multiple choice question:

> Justine has a bag with 12 blue marbles, 6 green marbles, 8 purple marbles, and 4 red marbles. If she wants the probability of picking a blue marble to be ½, what should Justine do?
>
> (a) add two green, two purple, and two red marbles;
>
> (b) add two blue marbles;
>
> (c) remove one green, one purple, and one red marble;
>
> (d) add six blue marbles.

Despite the students' drawings, which included circles in a bag, only two of six groups answered the question correctly. Tracy redirected the discussion by saying, "What do you want the end result to be?"and by asking them to redraw their images: "It's okay if you draw circles, but I want to see a B in those circles." After had students returned to their groups to re-discuss answers to the problem, Tracy copied one of the group's drawings on the whiteboard (see Figure 4.15).

Tracy asked students to tell her what they noticed about this representation, to which students responded that there were six marbles in each row, adding after further prompting that there were two rows of six blue marbles and three rows of six non-blue marbles. Tracy concluded, “So what would I have to add to this one?” [puts hand over non-blue marbles], to which a student responded “one row of six” and subsequently identified A as the correct answer. Although the exchange ended there, one could imagine additional discussion of the strengths and weaknesses of students’ respective images, including how drawing the marbles in six rows enabled one group to quickly recognize a pattern that led to an answer. In contrast, drawing a realistic image of jumbled marbles in a bag did not as effectively support other groups’ reasoning about the problem, especially when they focused on the marbles as “circles” but not as colors, which was the defining characteristic of the problem.

As this example suggests, “visualizing” in mathematics is not synonymous with constructing a scene that aligns with what students would see in the world. The design of a visual display during problem solving shapes mathematical activity in crucial ways (Miera, 1995). Indeed, in this case, the iconic image of marbles in a bag served as a less useful representation than the abstracted representation of letters in rows. Karl extended this definition of “visualizing” even further when he compared numeric tables in mathematics to videos in social studies, arguing that they were both “quick, and [they’re] visual.” He then clarified:

> I say this all the time…in math when we have graphs and charts and things like that. You can give that information in a chart and people can look at it for a minute or so and they get the information. You can get that same information on paper written down, it might take a full page of paper, but they would have to read it. Their attention, their focus isn’t the same. So when we do little videos (in social studies), or when we do maps, or we

> show visuals, it's something that's quick, and that they can pick up on, and they can get that same information in a much easier way.

In this sense, when "visual" in mathematics is defined as any avatar whose appearance or spatial arrangement helps students to recognize patterns or solve problems, then "visualizing" in mathematics can entail the construction of many kinds of mental and external representations that facilitate an understanding of the "same information in an easier way." While these kinds of representations might include "videos" and "maps" in social studies, in mathematics, effective visualizing tended to be related to an image's ability to communicate patterns. Accordingly, teaching students to "visualize" as part of mathematics instruction might include questions such as, How might we show this in a way that would let us see patterns in what is happening here? What kind of representation would allow us to see what is happening in this problem? How effective is my representation at showing me patterns, and is there a more effective way for me to go about representing this?

Connecting

As with any discipline, students can draw from a wealth of personal experiences as frameworks for understanding the context of mathematical activity. Indeed, a lack of world experience regarding certain situations, such as Roth et al.'s (2005) example of students who did not understand the effect of waste water on shrimp populations, can contribute to students' difficulty in understanding word problems situated in those contexts—not to mention contributing to a lack of motivation to solve those problems when they are seemingly disconnected from their lives.

Although all disciplines can draw from different aspects of students' everyday experiences, the frequent use of numbers and symbols required a second type of connection:

point-to-point mappings as students learn how the structures and logic of one mode (e.g., the spatial layout of a coordinate plane; the structure of a three-dimensional rectangular prism) map directly onto another (e.g., the input and output values of a numeric table; the symbolic formula for surface area). As one example of this kind of instruction, Grace first introduced rulers by asking students to simplify various fractions in which the denominator was 16. Students came to the board and simplified all of the fractions, after which Christy asked them if they noticed any patterns across their simplifications (see Figure 4.16 for a recreation of what the students wrote on the board). The numbers' spatial placement, and the symbols on existing text (e.g., the circles) helped students to identify patterns, such as that every other fraction was not irreducible.

Grace then distributed an enlarged copy of a ruler to students. After they noticed that there were 16 tick marks between each of the numbers (e.g., between numbers 2 and 3), Grace continued:

> What I'd like you to do right now, take your pencil, and above each one, I want you to write the fraction. This one would be one sixteenth, two sixteenths, three sixteenths [points to individual ruler lines on the overhead]. All right. Now that you've gotten that written, let's look at these little lines. Tell me something that you notice about all of these lines. What do you notice about all of these lines? Everybody should be able to look up here and give me an observation about these lines.
>
> *Student*: It's smaller and bigger.
>
> *Grace*: So we've got some really short ones and then we've got some bigger ones.
>
> *Student:* It sort of looks like a pattern.
>
> *Grace*: There is a pattern, good. What else?
>
> *Student*: The longest one is in the middle, and it's bigger than all the rest.

Grace: The longest line is the eight sixteenths line, good.

Student: They all represent a fraction.

Grace: Good.

Student: They're all sixteenths.

Grace: They're all sixteenths, good.

Student: They're the same distance.

Grace: They're all the same distance apart.

Student: There's more than one pattern.

Grace: There's more than one pattern here. Let's start with the longest one, the one that somebody said was the longest. When we simplified eight sixteenths, what did that equal?

Student: One half.

Grace: So any time you're measuring and it comes to these long long lines in the middle [points to middle line and writes ½], you know that's going to be a half. Let's go to the next length of line. This line [points to middle line] represents a half, what do these lines represent [points to the two lines that are second longest].

Student: One represents one fourth, the other represents a half, no, three fourths.

Grace: Mm-hmm. So this is one fourth [labels line 1/4], and this is three fourths [labels line 3/4]. Where's two fourths? That doesn't make sense to have one fourth and three fourth but not two fourths. Where's two fourths?

Student: The half.

Grace: The half line. Why is that?

Student: One half equals two fourths.

Students repeated the process to observe that a particular length of line indicated eighths, but the half, fourth, and inch line also represented eighths. Grace's students then observed that the "little bitty lines were sixteenths," to which Grace prompted them to reconsider whether the longer lines were sixteenths, too. In the end, she recapitulated the students' observations of sixteenths: "So all of these lines are sixteenths [pointed to different lines on the ruler], but these [points to shortest lines] are the ones that can't be reduced."

In this exchange, which included explicit comprehension instruction on how to read the lines on one inch of a ruler, Grace demonstrated how the structure of these lines could be directly mapped onto numbers representing fractions—for example, the longest line related to the greatest number of equivalent fractions, the next longest lines related to the second greatest number of equivalent fractions, and the shortest lines represented sixteenths that could not be further reduced. Students not only learned how the two modes related in a general sense, such as "all [lines] represent a fraction….they're all sixteenths," but they also learned how individual, specific fractions (e.g., 7/16) related to individual, specific lines, which in turn related to other fractions and to the lengths of other lines.

Lemke (2003) has argued that numbers and symbols are best at conveying topological meanings, or precise meanings by degree. When numbers and symbols are connected to other sign systems—whether these systems are graphs, images, shapes, manipulatives, or something else, the maintenance of this precision often requires that a specific *this* (e.g., a single *tile;* a single *point*, a single *line*) correlates in some way with a specific numeric/symbolic representation. These connections between semiotic systems not only require a sense of the meaning and form of each mode, therefore, but of also of how two modes' structures in general can map on to each other in predictable, patterned, consistent, and precise ways.

Determining Salient Information

Reading numeric and symbolic combinations in mathematics is perhaps different from reading texts in other content areas wherein students can learn to use headings, topic sentences, and other features to distinguish superordinate ideas. Due to the discipline's historical push to eliminate anything "superfluous…which engages our mental powers to no purpose" (Descartes, 1952, p. 101), each mark in a symbolic combination is usually indispensable, whether it is a parenthesis, a line, a letter, or a dot. Looking for "important information" is therefore a unique task with this mode because all marks are essential to constructing conventionally acceptable understandings of the text's meaning.

In conjunction with numeric and symbolic combinations, mathematical texts can communicate meaning in many other ways: through their use of color, shape, size, length, words, and so forth, some of which are essential to understanding the point of a particular representation while others are not. In Tracy's example of the squares that represented residents' property lines, *size* was a salient factor, whereas *color* was not (e.g., the image could have been brown, white, or green and would have communicated the same idea). However, in the image shown in Figure 4.17 that depicts a piece of licorice divided twice, *color* was somewhat significant to understanding the activity represented by the text: The black lines represented the first round of division while the green lines represented the second round of division. The color purple did not represent anything in and of itself, but the purple circles showed how the licorice might have been divided, while only the color *red* was intended to serve an iconic relationship to a physical referent by representing a string of licorice.

Viegas and Wattenberg (2011), two leaders of Google's "Big Picture" project that addresses data visualization in a digital age, projected that color and other markers (movement, size) will become increasingly important in digital representations of numeric data. They recommended *Gapminder* (www.gapminder.org), a site in which moving colored dots represent countries—as one example of how color, size, movement, and user input can make data more appealing to contemporary viewers who have come to expect online interaction.

To be sure, markers such as *color* and *size* are not always salient in mathematical representations, nor do they always mean the same thing, but students can learn to attend to these features, first by asking the question, What is this representation all about? (Roth, Pozzer-Ardenghi, & Han, 2005); and secondly, by generating specific questions about different sub-components of mathematical representations, including:

- Does size stand for something? If so, what?
- Why are some components bigger than others?
- Does color stand for something? If so, what?
- Does movement mean something? If so, what?
- What is this representation comparing and how does the text-maker indicate that comparison?

As these examples suggest, mathematical representation encompasses far more than strings of black and white numeric equations. Accordingly, instruction on how to read and generate representations can attend to a wide variety of features that are key to a text’s meaning, including discussions about which features are essential to the author’s point and which might be superfluous or merely decorative (cf. Tufte, 1990).

Predicting and Checking Predictions

Predicting is a key tool of mathematicians’ practice, from estimating the solution to a single problem, to making and checking conjectures about patterns that might hold true across a set of numbers. Karl's students, for example, noted patterns in numeric tables showing x and y values to conjecture that a straight line on a graph represents an increase or decrease at a constant rate. Tracy's students used fraction strips (see Figure 4.18) to make conjectures about the denominators of fractions that were equivalent to one half. As a third example of predicting, Grace's students graphed four different equations (see Figure 4.19 for the graphing of $y = x$, $y = \frac{1}{2}x$, $y = \frac{1}{4}x$, $y = \frac{1}{8}x$), each time predicting what would happen to the slope of each line as the number in front of the x became smaller.

To help her students predict what would happen as the number in front of the x increased, Grace said, "Now let's go the other direction. We've been using fractions. What else could we use?"

> *Student:* Whole numbers.
>
> *Grace:* Whole numbers. So let's go back to our [calculator] screen y equals, and let's type in something with a whole number. Let's do y equals 2x. Now what do you think this line is going to look like?
>
> *Student:* It's going to be like the highest one. The whole number is going to be steepest.
>
> *Grace:* You think it's going to be the highest, the steepest.
>
> *Student:* Like it goes far out at the bottom, and then it's going to be the highest. [Grace uses her arm as a slope showing that the line for 2x will be "higher" than the previous four lines in the first quadrant, but beneath the previous four lines in the third quadrant. Student shakes head yes.]

At the end of the exchange, Grace introduced the number in front of the *x* as *k* and asked students what happens to the line as k gets larger ("the line gets steeper") and what happens when k gets smaller ("the slope decreases and decreases").

As this example suggests, in mathematics, whose goals include generalization and the recognition of patterns, predicting can include synthesizing information across various sign systems to make conjectures about patterns that will hold true across the sign systems. Just as importantly, predicting in mathematics entails looking for instances wherein the prediction might be wrong, disproving the generalization or pattern. For example, the students were incorrect in saying “the line gets higher” as *k* increased, because in the third (bottom left) quadrant, the line “got lower” than the other lines. By the end of the discussion, students had to adjust their language to note the slope became *steeper* as k increased, repeatedly testing their conjectures using different *k* values. In this way, predicting in mathematics can include repeated, strategic tests of a prediction, often as it is represented through multiple sign systems.

Representational Practices Specific to Mathematics

In mathematics, assessment was characterized by a kind of semiotic congruence in the sense that students were largely assessed through the same modes that teachers used for instruction: primarily, numbers and symbols, and secondarily, images and written words (see Figure 4.20). Though teachers sought to foster conceptual understandings of what number sentences *meant,* students still required explicit instruction on how to translate concepts they were learning about (such as dividing wholes by fractions) to symbols on a page. In writing of the challenges and peculiarities of learning this symbol system, Giaquinto (2007) argued: “Manipulation of symbols is just as spatial as geometric thinking. Operations depend on spatial features and input symbol array. Symbolic thinking falls within spatial thinking” (p. 241).

In accordance with this idea, teachers provided explicit instruction on how to place numbers and symbols on a page in order to help students solve particular problems numerically, often after they had done activities to indicate the meanings behind those numeric problems. This type of spatial instruction on how to organize symbols on a page included:

• writing fractions and ratios as $\frac{2}{6}$ rather than 2/6 to enable students to perform later operations with them, such as simplifying or finding proportionate ratios

• writing two fractions vertically rather than horizontally in addition and subtraction problems to enable them to find common denominators to the right of the original fractions

• writing fractions horizontally rather than vertically in multiplication and division problems to enable students to easily see patterns across the numerators and denominators

• placing multiplication dots visibly higher than decimal dots

• writing numbers before letters in equations (e.g., 4x instead of x4)

• placing dots between numbers to represent multiplication, even though multiplication can be represented with no symbol, when translating from part of a formula (e.g., *lwh* to 4•2•4 instead of 424)

• writing the formula first and using it as an organizer for writing the numeric solution

• writing each step of a numeric solution line by line, with a new line for each operation performed

• writing a cursive *l* instead of l for *length* so it would not be confused with one

• writing a multiplication sign as a dot instead of as an *x* in equations to avoid confusion with the variable *x*

• writing numbers vertically when adding and subtracting while adding implied decimals and aligning place values

• using graph paper to assign each number to a box when students were not successful at aligning appropriate place values in division problems

• leaving space above, beneath, and to the sides of different numeric problems

• circling certain numbers (e.g., the bottom numbers on factor trees) to set them apart from others

• placing numbers in spatial configurations (including but not limited to tables) that enable students to see patterns and anomalies (see Figure 4.21)

This type of writing instruction alone would not lead to conceptual understandings behind symbol manipulation. Nonetheless, because students may initially have a tenuous grasp on newly learned mathematical concepts, the teachers did not want them to become confused due to misunderstandings related to the placement and appearance of symbols. If numerals "do some of the thinking" (Wertsch, 1998) in performing operations and reasoning about problems, then this explicit attention toward their spatial and visual appearance was perhaps essential to move students toward ways of thinking that aligned with the conventions of the discipline.

Teaching the writing of numbers and symbols was a complex task in its own right, related to students' understandings of the tasks they sought to accomplish, to numbers' visual appearance, and to mathematical notations that had been established by convention. Teaching students how to use written words to explain their mathematical reasoning also proved to be a demanding task, with 50-minute periods devoted to writing a single sentence containing an accurate mathematical description or conjecture. This type of instruction is aligned with recommendations by the National Council of Teachers of Mathematics (2000) to "formulate generalizations and conjectures about observed regularities" and "construct and evaluate mathematical arguments" (p. 268).

Connolly (1989) recommended the use of more informal writing assignments as well, including writing tasks such as explaining errors, explaining metacognitive processes, asking questions, summarizing, defining, keeping learning logs, and so forth. He contended that natural language in writing or speech operates “as the metadiscourse of all of our other symbol systems [and] enables us to distance ourselves from our mathematical problem solving and reflect on our procedure” (p. 22), claiming that students should become comfortable with writing often about “other symbol systems” in this discipline in ways that reflect their own natural language and not just the technical vocabulary used in mathematics.

Karl, Grace, and Tracy asked students to use writing for similar purposes. For example, students annotated word problems, writing questions to the side and making lists of important information as a precursor to solving problems, at times summarizing what they did at the end or explaining errors in their own or others’ work. As an another example of informal writing designed to help students articulate their thought processes, Tracy’s students played the “Factor Game” (See Figure 4.22) several times before Tracy asked them to write a “Tips: How to Play to Win the Factor Game” piece analogous to secret tips to win at Nintendo and X-box games in which they explained to would-be players how to get the most points.

Although these examples of writing enabled students to express their reasoning relatively informally, with no instruction by the teacher as to how to move toward more precise mathematical language, other examples document teachers’ instruction designed to move their students toward using mathematical terms to explain patterns they noticed in numbers and images. One excerpt from Tracy’s instruction will show how she supported students’ development from everyday language to mathematical vocabulary as they wrote about patterns they noticed across fractions.

Tracy began the lesson by instructing students to “use your fraction strips to see how many fractions you can make that are equivalent to ½” (see Figure 4.18) and to write an answer the question, “What do you notice about the denominators of all of these fractions?” Tracy then stated that, as she walked around and observed the groups’ written descriptions, most people had written “they are all even” to state what they noticed about the denominators. Tracy wrote “they are all even” above students’ equivalent fractions on the whiteboard (see Figure 4.23) and continued:

> I thought it was a great observation. I’m going to write it on the board, and I want you to talk about it in your group to see what you could have done to make it just a little bit better…. I want to see if you can use the word *multiple*, and I want you to use the word *factor*. So see if you can come up with something that uses both of these words.

After students discussed their responses in groups, Tracy continued: One thing that could make this sentence better already.

> *Student:* Instead of *they*, you could write denominator.
>
> *Tracy:* Instead of *they*, you could write *the denominator* [crosses out *they* on the board and writes *the denominator* underneath it]. Even if we change *they* to *denominator,* could we still change the sentence to be a little bit more specific? We had this conversation during our special numbers project. If I asked you if the numbers were even and odd, people were able to give me examples of even and odd numbers, but it was hard for them to explain what it meant in words. [Tracy circles *even* on the board.]
>
> *Student*: It’s composite.
>
> *Tracy:* Are all of those up there composite?
>
> *Student:* Not one half.
>
> *Tracy:* Aha! But all of the other ones have a composite denominator. Who has a good sentence with the word multiples? What does an even number mean?

Student: It means that it can be, that it can go into, wait no, that two can go into it, because like if say you have 48 you can multiply two times something to get 48.

Tracy: Very clear explanation. He said that if it's an even number then two can go into it evenly and then he gave an example. So how can we use the word multiples to make a sentence here? [Students further discuss their answers in groups.]

Tracy: Which group thinks they have a really great sentence?

Student: All the denominators are multiples of two.

Tracy: How do you guys feel about that? [Students give the thumbs up sign and Tracy writes *All of the denominators are multiples of two* under the sentence *They are all even.*]

Tracy: Okay, can we make a sentence using the word factors? One minute to make a really great sentence using the word factors.

Student: All of them have one half as a factor. [Tracy writes *all of them have 1/2 as a factor*] on the board.

Tracy: All of them have one half as a factor. Look at the sentence for just a second. Are we talking about the entire fraction? No, what are we talking about? The denominators. First of all, instead of the word *them*, what should we have used?

Student: Denominators.

Tracy: All of the denominators have one half as a factor. Talk about that with your group. How do you feel about that sentence? [Students talk in groups.]

Tracy: All right guys, so I heard some good conversations. I want to clear something up, when we're talking about factors and multiples, we're talking about whole numbers, not halves and thirds and fourths and fifths. Is there something here we could use instead of one half? We could say, all of the denominators have what as a factor?

> *Student:* All of the denominators have two as a factor.
>
> *Tracy:* All of the denominators have two as a factor. Do you feel good about that statement, bad about that statement? [Students hold their thumbs up to indicate they felt good.]

In addition to adhering to what many mathematicians consider to be characteristics of effective writing in mathematics—such as brevity and economy of expression, consistency with other established theorems of mathematics, precision of language, and correct use of mathematical terminology (e.g., Kline & Ishii, 2008)—this excerpt exemplifies at least two characteristics of Tracy's formal writing instruction in this discipline. First, it was tightly intertwined with other modes: in this case, the manipulatives and the written symbols that both served as a precursor to generating the written description. Second, just as students were encouraged to express the same idea in multiple modes throughout the year, so too were they encouraged to write (and speak and think) about the same patterns and concepts using different words. In this case, students considered how the concept of *even numbers* could be expressed in terms of both *factors* and *multiples*, suggesting that asking students to *restate in another way* in mathematical writing might foster more flexible ways of thinking.

In this example, Tracy's students ultimately expressed their understandings in writing without an explicit effort to integrate the manipulatives or the symbolic notations into their written descriptions. Another example will indicate how Grace explicitly taught her students to integrate multiple sign systems in constructing mathematical explanations. After students had learned about solving one-step equations through the use of manipulatives and numbers, Grace drew a three-column chart on the board with three headings: Model, Algebraic, and Explanation. In the first column, she drew a picture of what the manipulatives would look like for the first step of an equation; in the second column, she wrote the numeric equation; and in the third column she explained (through written language) what was happening in the first two columns. Students used her example to construct their own explanations of other equations.

In this example, Grace's writing instruction explicitly addressed how to integrate different modes through the use of vertical lines that separated them. The use of horizontal lines also combined them while concurrently signaling a transition to a new step or action. This type of writing instruction differed from transitions in word-based texts, which can be indicated instead through other means, such as phrases, headings, or new paragraphs. Instead, in this instance, concepts that were the "same" or "different" were communicated in part through spatial placement in relation to one another.

Ainsworth (1999) suggested that students who only use one mode to mediate and explain their mathematical thinking tend to develop more shallow understandings than students who can use multiple representations to explain the same concept; yet many students do not intuitively know how to use labels, space, color, or other markers to show how these mathematical representations are related. This type of explicit instruction on how to integrate words, images, tables, graphs, and/or numbers—using them to co-refer to each other—may help students think about how to construct arguments, descriptions, and explanations and can be beneficial as a means to ensure that students are not stuck with one representation as their only access to a mathematical concept. This type of writing instruction would require students to know how different representations relate to each other in expressing mathematical understandings.

Critical Numeracy and Literacy Instruction

Many researchers (e.g., Fahseh, 1982; Lemke, 1990) have asserted that the disciplines of science and mathematics can seem "forbidding and obscure" (Halliday, 2004, p. 159) by removing themselves from many students' everyday languages and replacing them with so-called "science speak" (p. 242), language with highly specialized vocabulary and grammatical structures. One characteristic of this scientific and mathematical discourse is its tendency toward a *high degree of modality* or certainty and authority assumed in the text. *A straight line connects any point to another point*, for example, is assumed to be true, while a statement such as, *I believe this might be a line* indicates a lower degree of modality as the author assumes a position of uncertainty.

Although these forms of certain discourse permeate the sciences, they are perhaps even more pronounced in mathematics where acknowledgement of authorship and traces of visible human activity are even further removed from texts. For instance, take the simple example of the symbol combination *4(2)* that represents actions such as multiplying; doubling one group of four; or quadrupling one group of two. This symbol combination removes all perceptually visible action, such as a person giving four pieces of candy to a friend who already has four pieces of candy, or four siblings whose parents buy them each one pair of shoes.

As another example, consider the equation $m=1.5k$, similar to those used in the teachers' classrooms. When numbers and symbols are repeatedly decontextualized from familiar situations, it becomes difficult to question, *Does m really equal 1.5k? Should m equal 1.5k? Why does m equal 1.5k?* In this type of text, *m is 1.5k* because the anonymous author of the problem said so. In this way, the equation serves as an unquestioned and unquestionable starting point for further mathematical activity. In contrast, the sentence, *For every dollar I make, Joe makes one and a half dollars* enables students to ask critical questions about why that might be so.

For this reason, then, an important step toward critical numeracy is *contextualized* numeracy, one that acknowledges that, although numbers and symbols can represent abstractions with no physical referent, they are used in very real situations as part of larger arguments to try to adopt people to accept certain beliefs, make certain purchases, and take certain actions (Stoessiger, 2002; White, Mitchelmore, Wilson, & Faragher, 2009). Indeed, Halliday (2004) argued that mathematical communication is among the most persuasive forms of communication in many contemporary societies due to this authoritative weight and seeming objectivity, one that is fostered in school-based texts when mathematics is presented as a series of *known postulates, given expressions,* and so forth, rather than as a set of *arguments* whose forms are designed to persuade people to adopt a certain viewpoint.

In many ways, recommendations for critical literacy instruction in mathematics echo the critical readings of any texts using questions such as those recommended by Luke and colleagues (Luke, O'Brien, & Comber, 1994, p. 143): *Who produced it? For whom? Why has it been produced? What is the author trying to do to you? What are the implications? What wasn't said about the topic*? While keeping these larger questions in mind, critical numeracy in mathematics can entail an additional set of questions such as:

- Why did the author choose this type of graph, and how would a different graph make the data look different?
- How do the authors use labels and words to frame the numeric or graphical representation in a particular way? How might other labels or words frame the issue in a different way?
- Why did the authors use this particular interval for the graph, and how would a different interval make the graph look different?
- What has been lost or gained in the transformation of data? What were the data like before the transformation?

• How might I represent the same data in a different way?

Tracy began to move toward this type of critical numeracy during a Halloween lesson wherein her students read the graph from Figure 4.24 and wrote “a spooky story” to explain the rise and decline of the vampire population in the 1800s. Recognizing vampires’ sudden demise around 1830 to 1840, one group offered divergent explanations of the phenomenon, ranging from the birth of a vampire slayer to a corresponding increase in the werewolf population. In this activity, students implicitly practiced graph-reading as an act of subjective interpretation, using the same mathematical representation to support different explanations.

One could imagine extending this activity to issues relevant to students’ communities, showing how numeric representations are used to prove particular arguments and asking students how they might explain the same representation in a different way by presenting it in different terms. For example, using Grace’s lesson on basketball statistics as a starting point for this type of discussion, students could use graphs, charts, written arguments, numeric representations, photographs, and other representations to make an argument about who was a better player—Kobe or LeBron—leading to a final discussion of how different “measures” of success (e.g., number of games won, ratio of games won to games lost, number of points made per game, ratio of shots made to shots taken, number of points made throughout one’s career), when framed in different ways, can be employed to prove a particular stance.

Tracy’s series of lessons on data representation provides another starting point for critical numeracy instruction. Tracy began by splitting the class into seven groups, each group surveying 25 classmates of their choosing as they asked a different multiple-choice question such as *What is your favorite food to eat at the movies? A. popcorn; B. licorice; C. pretzels; D. Junior Mints.*

Students first made a bar graph showing the relative number of people who liked each treat, then converted their fractions (5/25) to percentages to report their final results as a circle graph.

To expand this lesson on data representation, one could imagine two groups asking the same 25 people the same question with a slightly different set of responses (*nachos*, *pretzels, candy*, *slushies*) and discussing why their resulting pie charts were different, or two groups asking the same multiple choice question to two different groups of 25 people and discussing why their results were different as well. Students could then apply what they learned to national statistical reports, such as the claim that "Nationally, 60% favor letting local police stop and verify immigration status," as they note how these final numeric reports can be influenced by the way that the question is worded and/or the issue is explained; and the size and composition of the sample population. Just as students can question the seemingly factual claim that "80% of sixth graders at our school say that candy is their favorite food to eat at the movies" by experiencing how that claim was constructed, they can learn to question broader political claims that transform qualitative data into quantitative data.

Chapter Summary

Mathematics as a discipline relied on the regular integration of a variety of sign systems: written words, numbers and symbols, pointing gestures, and a variety of images and manipulatives. The regular integration of numbers and symbols, a mode designed for the execution of many problems, called for particular types of semiotic practices. First, this mode required specific, point-to-point mappings between it and other modes. To help students make these connections, teachers often relied on pointing gestures and color. Second, teachers included visual representations such as manipulatives and images to illustrate the kinds of mathematical activity that was "arrested" in this mode, which left no perceptually visible trace of action. Third, this mode required a particular type of representational instruction that included specific attention to numbers' spatial placement, an emphasis on saying the "same" thing in a different way, and attention to how students might integrate numbers with other modes as they constructed an argument or wrote an explanation.

Although images grounded mathematical activity as *visible activity,* many of them were still abstract in the sense that they used color, straight lines, and other markers removed from students' everyday perceptual reality. Strong critiques have been written against the presentation of mathematics as an *acultural* activity in the sense that this discipline might not draw from students' home languages, draw from students' everyday knowledge of mathematics, or apply mathematical reasoning to pressing problems in students' communities. This chapter suggests that this view of mathematics as *abstraction* is also instantiated through the representations that are used such as the absence of photographs. It concludes with a vision of critical numeracy that would encourage students to question the high modality of many mathematical arguments and that would allow students to use numeric arguments along with writing, images, and other representations to persuade people to adopt particular stances about issues they are interested in.

Table 3

Texts Used in Mathematics in 145 Instructional Episodes

Written Words (n=146)	Non-written Texts (n=365)
Instructions: 61	Numbers and symbols: 119
Word problem: 28	Gesture: 74
Multiple choice questions: 17	Geometric shape: 41
Label: 13	Symbols on existing text: 23
Question: 10	Drawing: 19
Definition: 7	Table: 14
Informational paragraph: 4	Manipulative: 13
List: 3	Graph: 12
Narrative: 2	Number line:9
Poem: 1	Coordinate plane: 8
	Geometric object: 8
	Object: 8
	Measuring instrument: 6
	Graphic organizer: 4
	Photograph: 3
	Map: 2
	Moving image: 2
	Embodied representation: 1

Mathematical Action
How am I going to go about solving this problem?
How do I solve process problems?
How do I use factors and multiples?
How do I find LCM?
How can I represent a fraction using paper?
How do I add and subtract fractions?
How do I add and subtract mixed fractions?
How do I multiply fractions?
How do I perform operations with fractions?
How can I find equivalent fractions?
How do I work with fractions?
How do I multiply mixed numbers?
How do I multiply and divide mixed numbers? (x3)
How do I perform mathematical operations with fractions?
How do I use multiples? How do I simplify fractions?
How do I use proportions to solve problems?
How do I use proportions with scales?
How do I change fractions to percents to decimals?
How can I apply decimals in the real world?
How do I multiply and divide decimals?
How do I convert units of measure?
How can I determine appropriate units of measure?
How do I find area?
How do I find circumference, area, and perimeter?
How do I find area and volume?
How do I determine the surface area and volume of a solid? (x3)
How can I create a "suit" for a solid?
How do I figure out a figure?
How do I find rotational symmetry?
How do I use T-charts to organize information? (x2)
How do I add and subtract integers?
How do I subtract integers?
How do I solve equations? (x3)
How do we solve systems of equations?
How do we solve inequalities? (x2)
How do we work with linear equations?
How do we use angle relationships? (x2)
How do we use exponents and square roots?
How do we rearrange formulas?

Conceptual Knowledge
What is slope?
What is a ratio?
What is symmetry?
What is my special number?
How can I deepen my understanding of factors and multiples?
How are fractions, decimals, and percents related?
When is it appropriate to use fractions? Decimals? Percents?
How do I interpret data from a graph?
What do I know about algebra?
What do I know about geometry?

Test Preparation (x3)
Are you ready for the CRCT?
What have I learned this year?
What do I need to know for the exam?

Figure 4.1. Essential questions in mathematics.

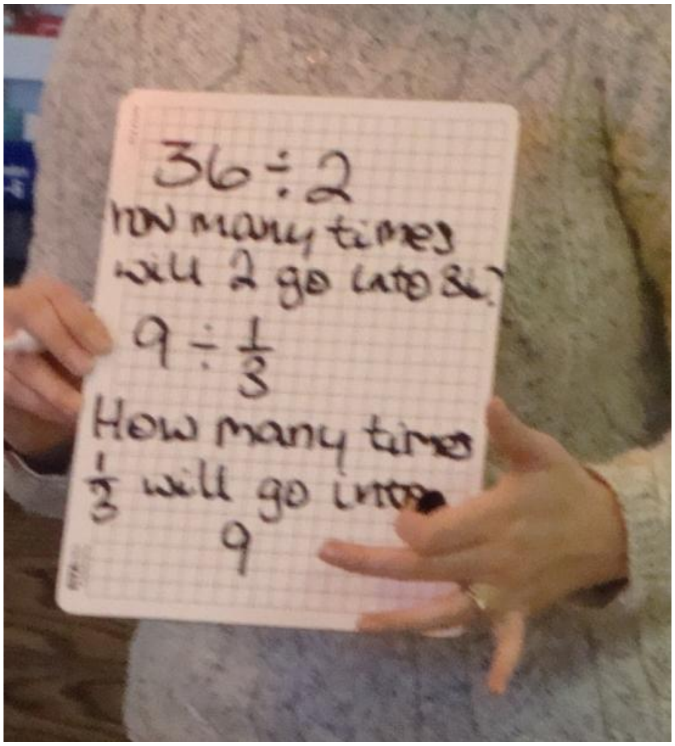


Figure 4.2. Numeric expressions represented in written words. Tracy wrote a familiar numeric expression—(36 ÷ 2)—to help students see how an unfamiliar expression—($9 \div \frac{1}{3}$)—was similar in structure.

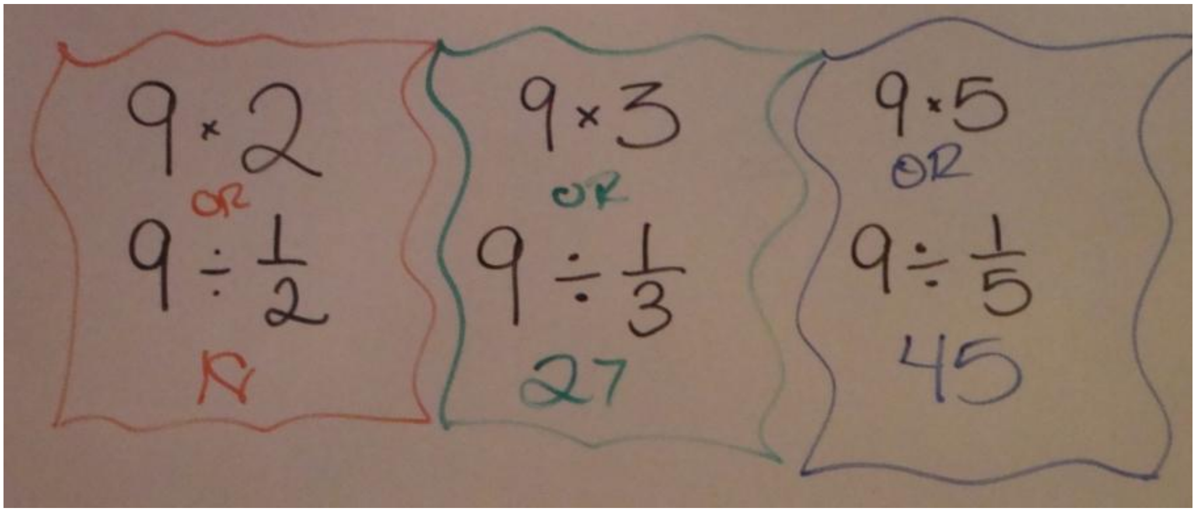


Figure 4.3 Numeric pattern showing similarities among three division problems.

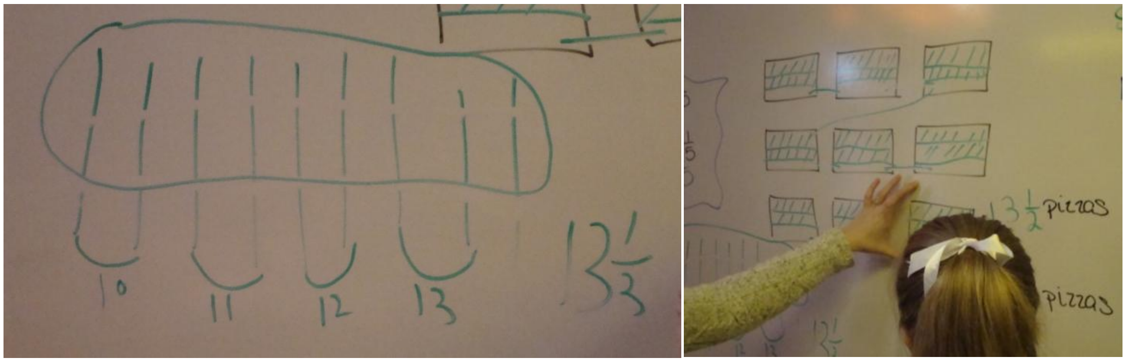


Figure 4.4. Student images representing nine bars split into groups of two thirds.

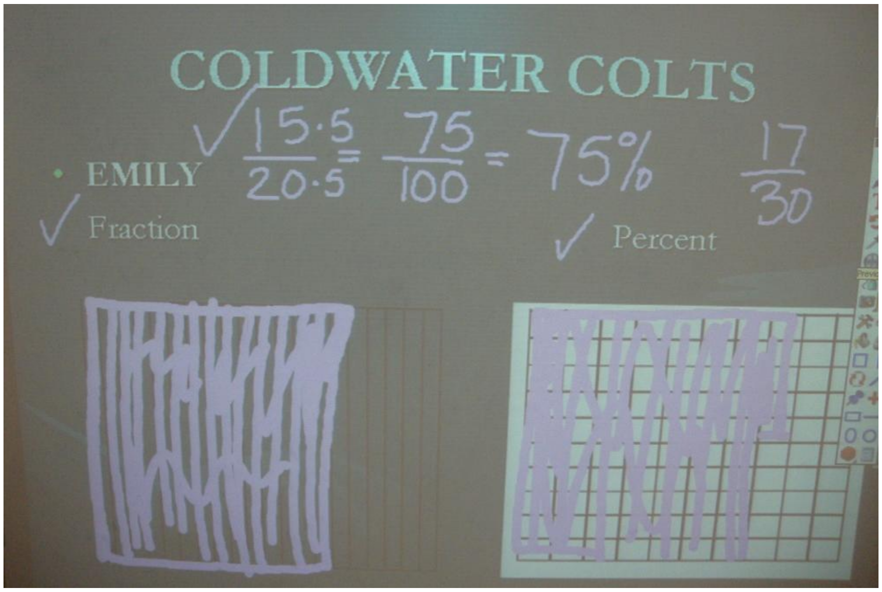


Figure 4.5. Two images relating fractions to percents.

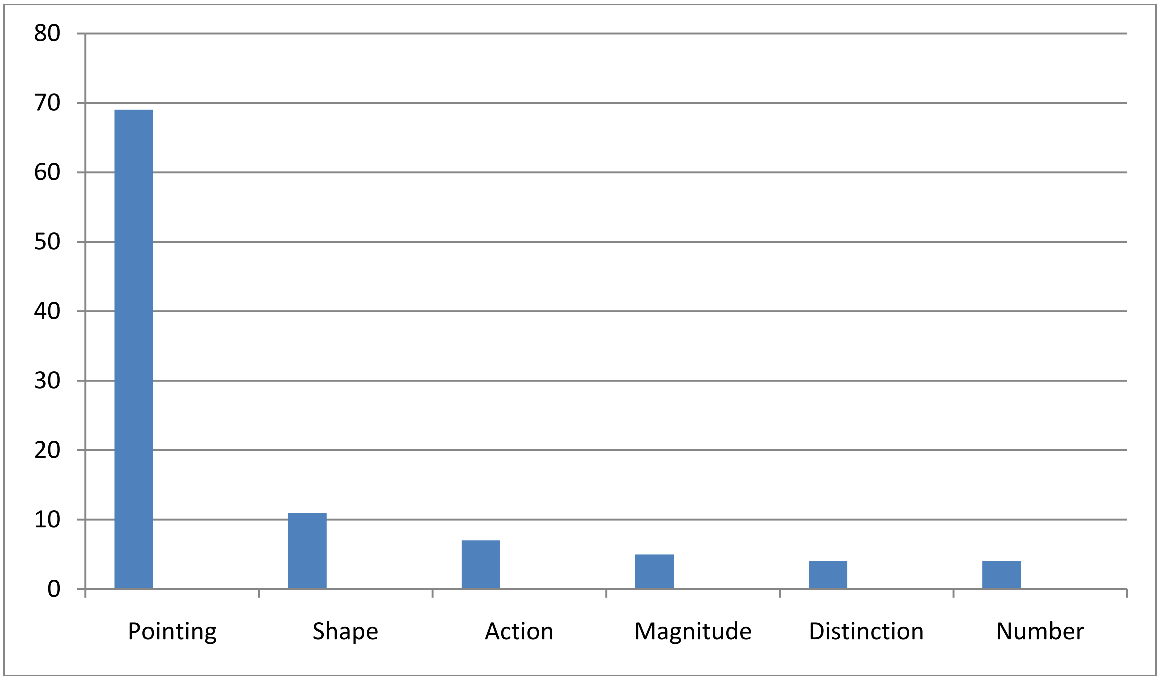


Figure 4.6. Types of gestures used in mathematics.

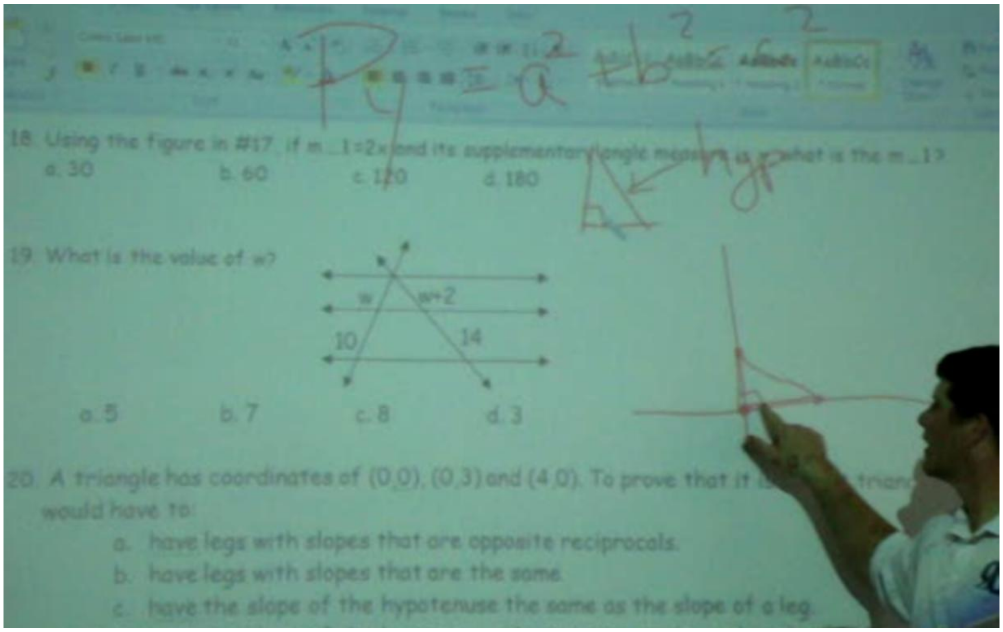


Figure 4.7. Pointing mediated among multiple representations.

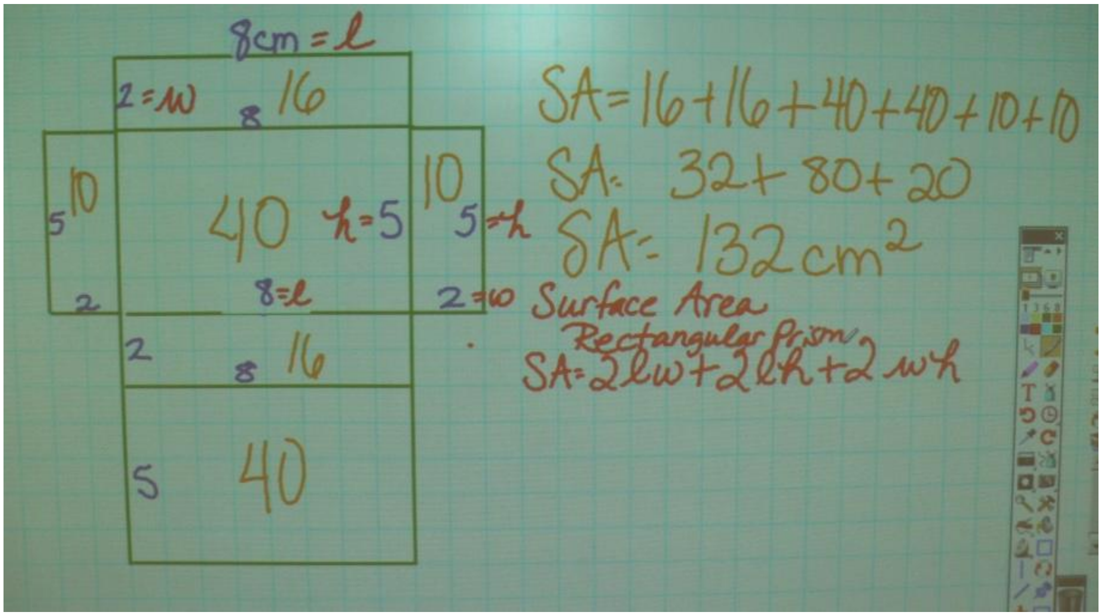


Figure 4.8. Pointing showed connections among different mathematical representations. These representations included lines on the drawing, specific numbers in the solution, and specific components of the formula for the surface area of a rectangular prism.

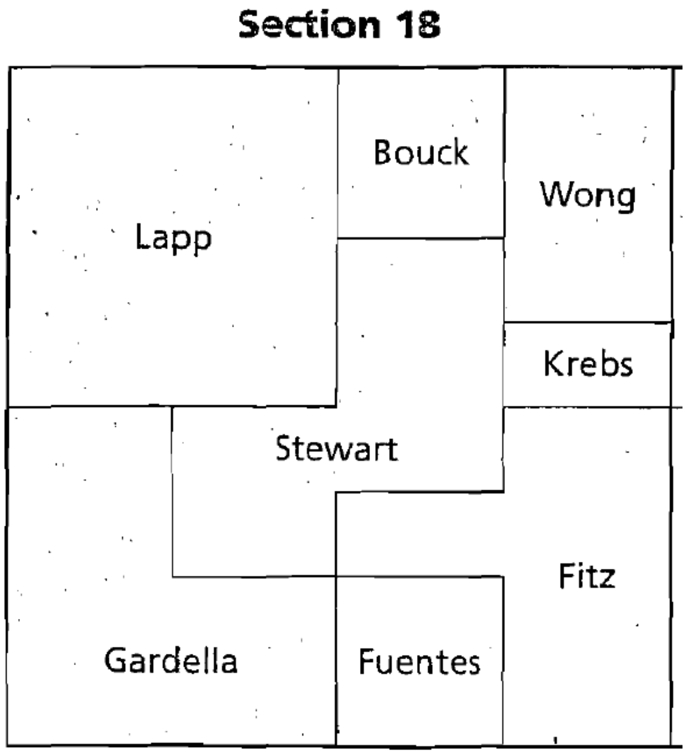


Figure 4.9. Image used to represent the fraction of land owned by each person.

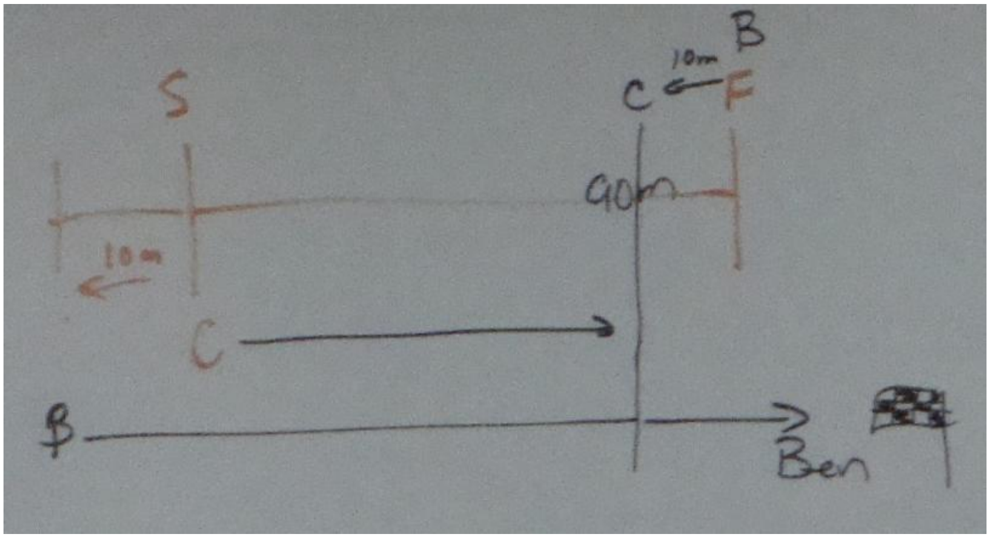
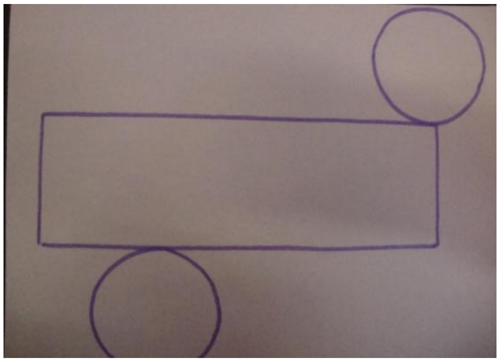
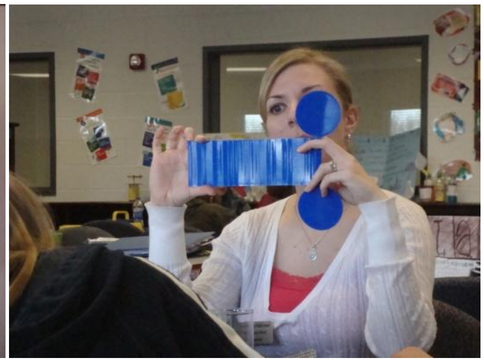


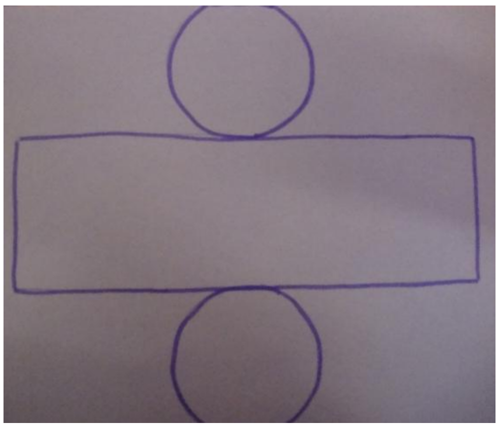
Figure 4.10. Mathematical image representing a foot race.



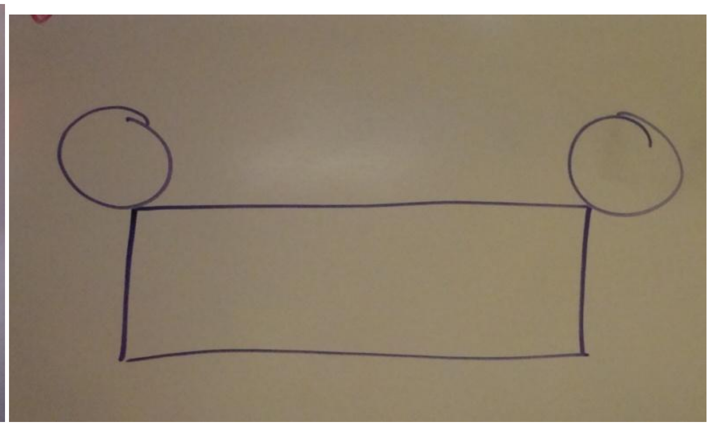
Potential Cylinder 1



Potential Cylinder 2



Potential Cylinder 3



Potential Cylinder 4

Figure 4.11. Potential cylinders.

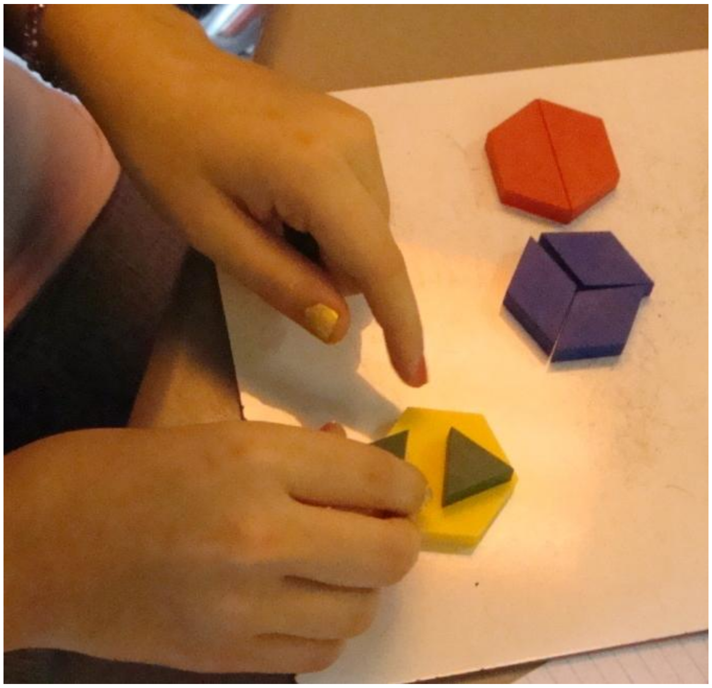


Figure 4.12. Fraction blocks used for addition and subtraction.

$\frac{\text{Jolly Ranchers}}{\text{Sweet-Tarts}} \quad \frac{4}{6} = \frac{J}{51} \qquad \text{and} \qquad \frac{\text{Sweet-Tarts}}{\text{Jolly Ranchers}} \quad \frac{51}{J} = \frac{6}{4}$

Figure 4.13. Color used to teach the ratio of Jolly Ranchers to Sweet-Tarts.

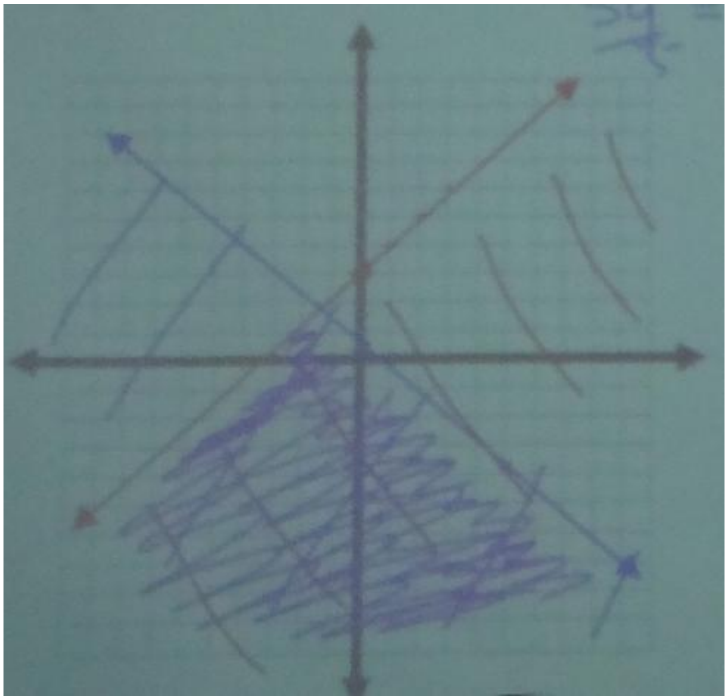


Figure 4.14. Color used to graph inequalities.

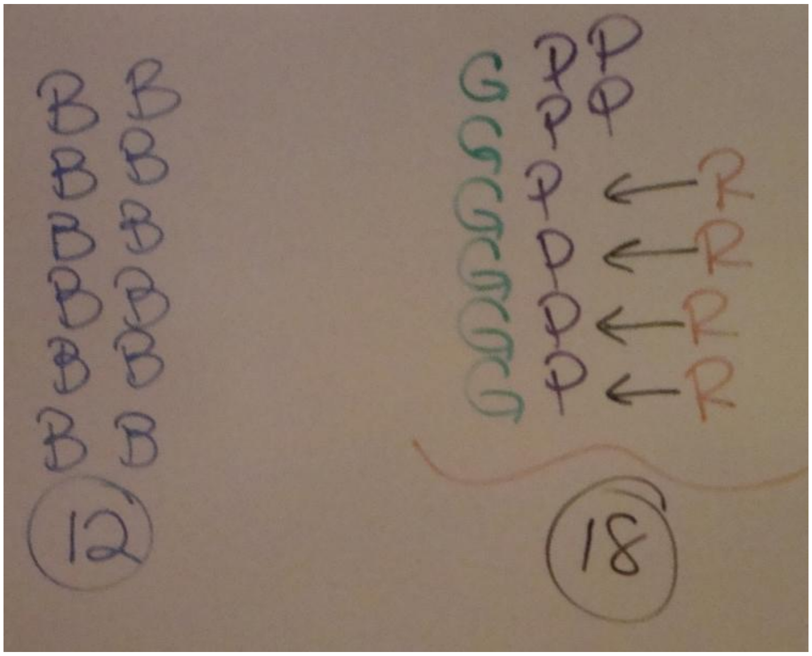
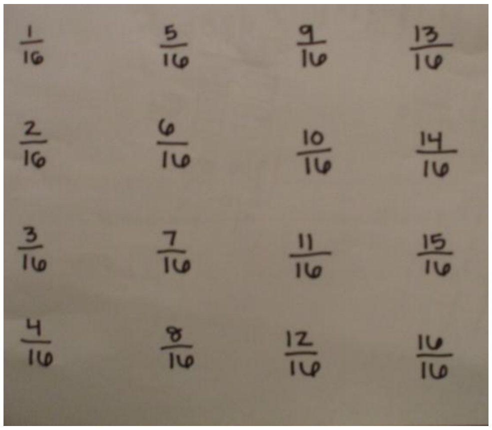


Figure 4.15. Image of marbles used to solve problem involving probability.



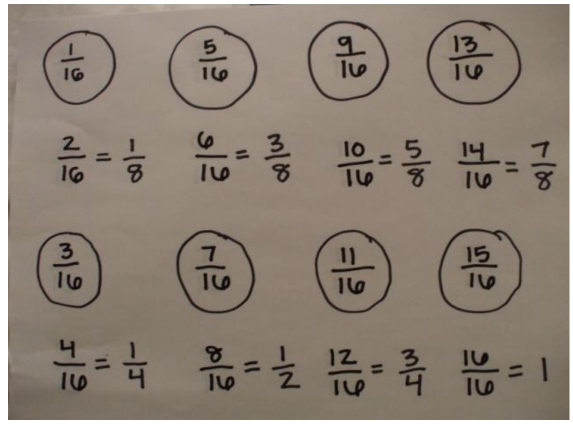


Figure 4.16. Rows of fractions designed to enable the easy viewing of patterns.

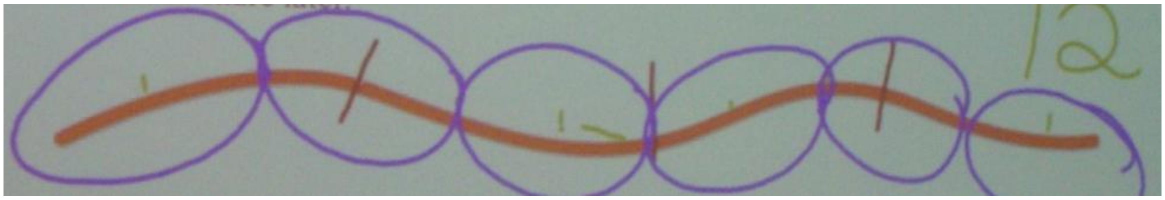


Figure 4.17. Two divisions, denoted by color, of one string of licorice.

Figure 4.18. Fraction strips.

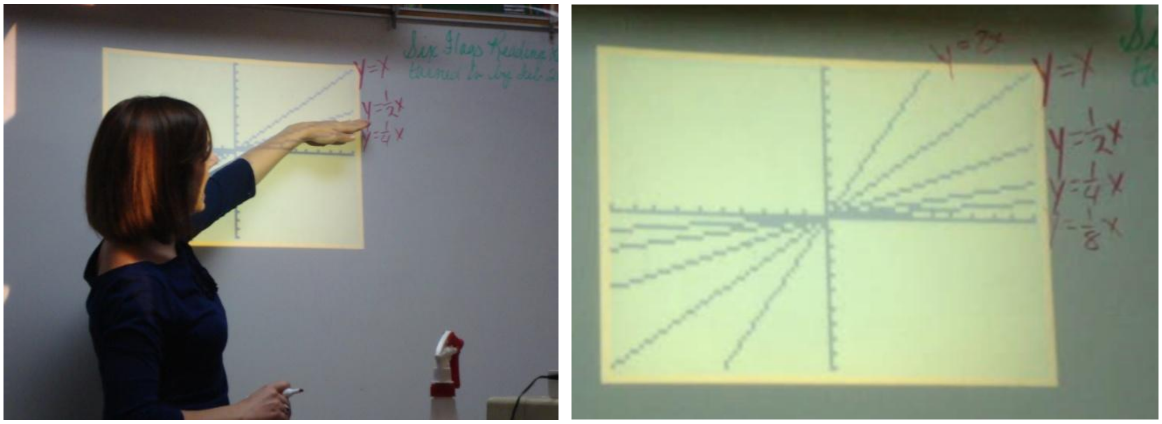


Figure 4.19. Patterns in slope lines.

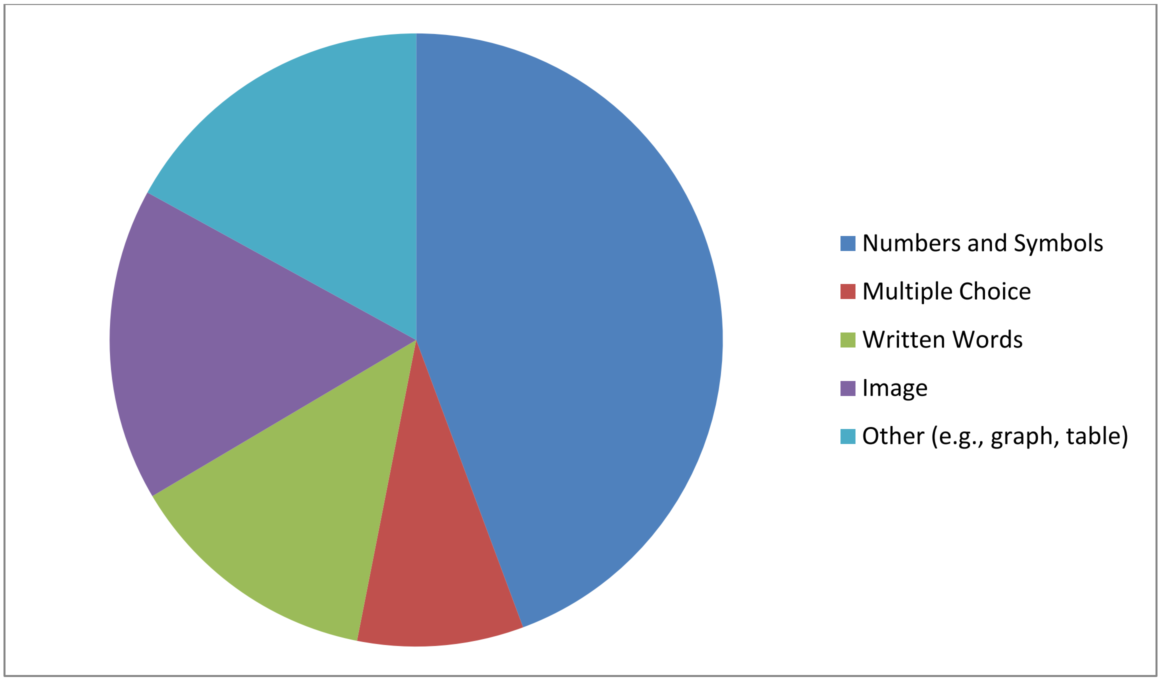
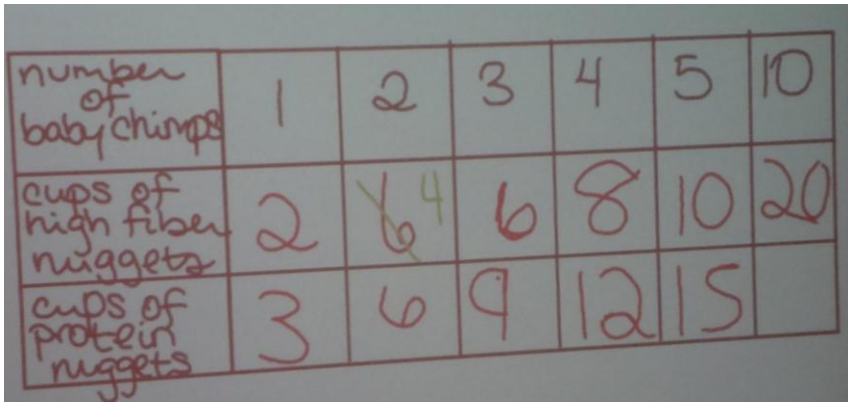


Figure 4.20. Modes used for assessment in mathematics.



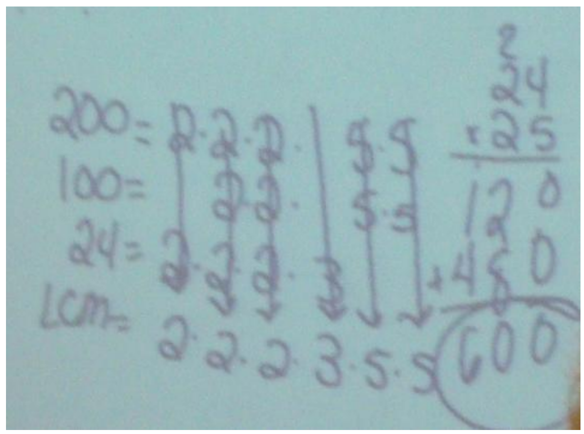


Figure 4.21. Spatially placing numbers in ways that enabled viewing of patterns.

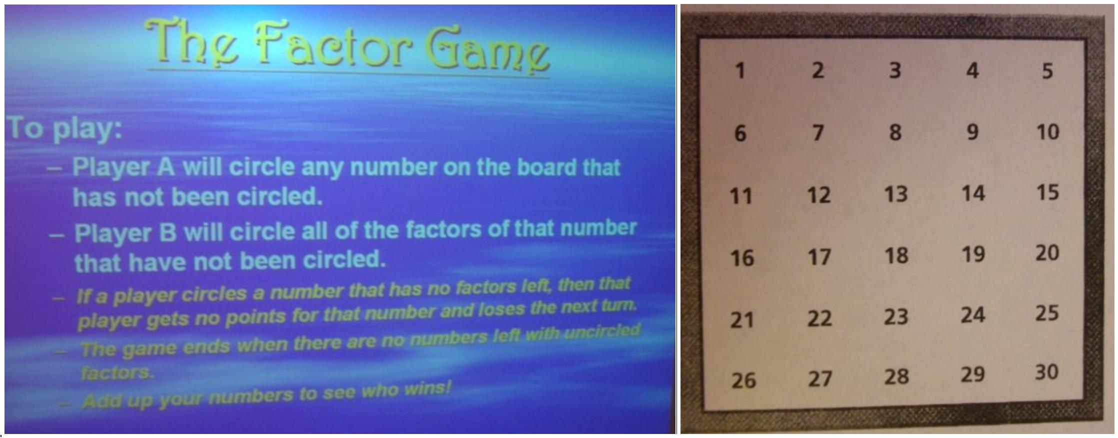


Figure 4.22. Game board and instructions for the Factor Game.

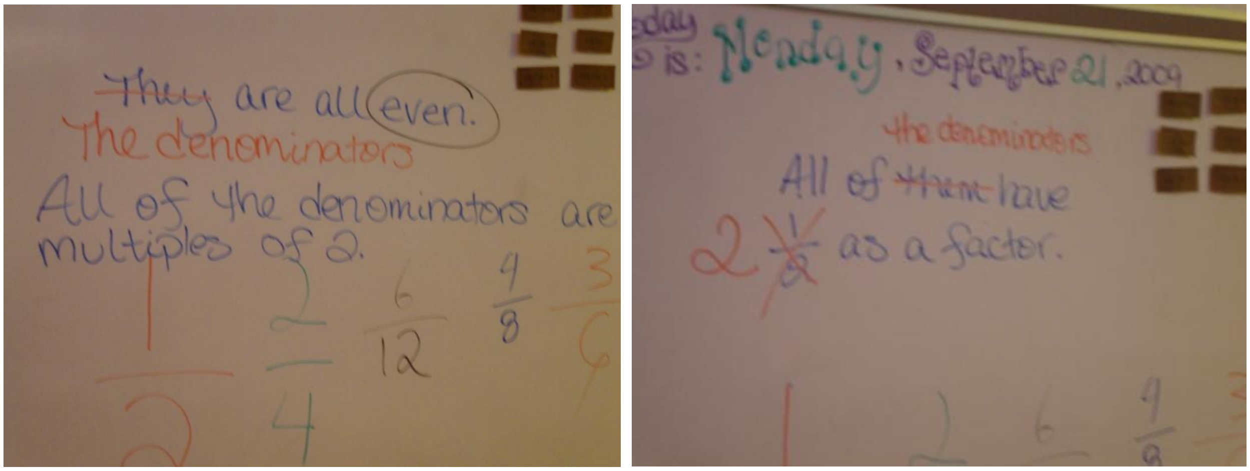


Figure 4.23. Patterns students noticed in the denominators of equivalent fractions.

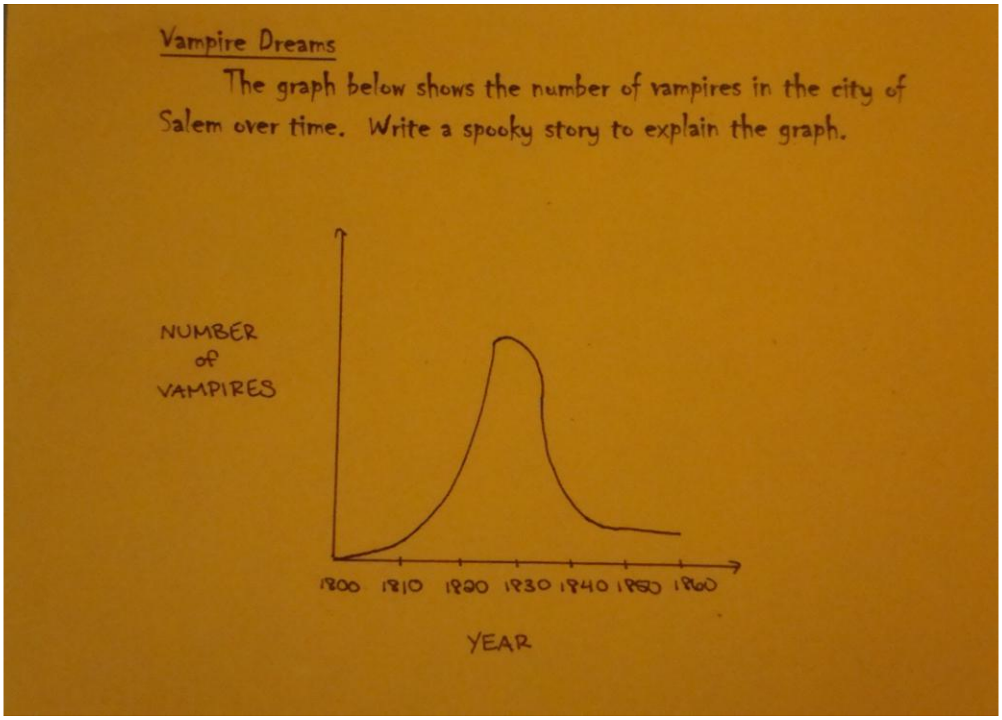


Figure 4.24. Line graph showing changes in the vampire population.

CHAPTER 5

IMPLICATIONS FOR DISCIPLINARY LITERACY INSTRUCTION

The preceding chapters of this book point to one fundamental idea: Different disciplines, in their efforts to communicate particular bodies of content, are instantiated through distinct forms of representation. Disciplinary goals for communication shaped students' and teachers' body movements as they used particular types of gestures to varying extents in each discipline, such as movement gestures in earth science, pointing gestures in mathematics, and action gestures in English. Disciplinary goals for communication shaped the types of images that were used in each discipline, such as photographs in earth science, illustrations in English, and patterned drawings in mathematics. Disciplinary goals shaped the act of verbal readings, with expression valued in English and specificity valued when reading numbers in mathematics. In accordance with disciplinary goals, some modes appeared in some disciplines and not in others at all, such as labs and demonstrations in the only discipline concerned with physical composition.

Each discipline, as enacted by the seven teachers, could thus be seen as a particular *modal configuration* (Norris, 2009). Norris used this term to describe an individual act of communication, asserting that in any act some modes "are absolutely necessary for the social actor to perform this action" whereas others "are not as necessary, but are still used in a particular way in order to perform the action as the social actor does" (p. 87). As an example, she asserted that one person's *spatial position/posture* was not as essential for understanding a manual on how to assemble something whereas this same mode was essential when the same person was trying to accomplish a different task. When applied to a series of acts of communication—wherein people seek to accomplish a set of related tasks as outlined by state or national standards in each discipline—some modes seemed more “absolutely necessary” to some disciplines than others in ways that varied according to the set of tasks.

This view of a discipline as a *modal configuration* is not meant to imply that these teachers’ ways of enacting of each discipline would be comparable to other teachers’ enactments, nor that these teachers’ methods of instantiating each discipline were *good* or *bad, effective* or *ineffective.* However, this view of disciplines as *modal configurations* does point to the idea that disciplines can be characterized by particular collections of modes, with some modes carrying more informational weight than others, and with different modal configurations lending themselves to different kinds of literacy practices. The following section will speculate on the affordances and limitations of these modal configurations as a whole as they were used by the teachers in this study, and the chapter will conclude by outlining a vision for content area literacy instruction as *metarepresentational competence.*

Reconceptualizing Disciplinary Representations

A different kind of look at the concept of affordances will serve as an entryway to a subsequent evaluation of the modal configurations in each discipline as a whole. Kress (2003) has asserted that particular modes not only possess a particular set of affordances that are related in part to their physical properties—for instance, an image affords the visualization of space—but also that every mode instantiates a particular epistemological commitment—that is, a particular set of assertions about how one can come to know and express the world. This idea is consonant with Iedema’s (2003) assertion that different modes “privileg[e] different domains of human experience” (p. 134).

What does this concept mean when applied to content area texts? Consider an example from Grace and Tracy’s earth science instruction when the two teachers took their students outside on their respective school campuses to investigate examples of wind and water erosion. The natural world, when used as a text, was perhaps unnecessary if students watch a video that showed erosion over time more clearly than a one-day visit around their school campus.

The affordances of a mode, though, are not only related to what they can convey in relation to a referent such as erosion, but also what they can convey about the nature of knowledge itself. By walking around campus, picking up mulch, and holding rocks that been used to prevent erosion—the students participated in a different “domain of human experience” and a different version of *what it means to build knowledge in earth science* than they have by watching a video to learn the same concepts. In this way, labs, demonstrations, and the natural world not only afforded students with the ability to understand something about physical composition, but they instantiated earth science as a discipline wherein ways of knowing were related to ways of acting and doing.

Indeed, as the discipline with the most diversity in semiotic activity, earth science included representations that communicated many different legitimate ways of knowing, experiencing, and expressing the discipline as a whole. *Visual perception* was instantiated as a crucial way to construct and express knowledge in this discipline—from photographs that epistemologically grounded the discipline in ‘the world as it appears,’ to the positioning and movement of bodies in space that enabled types of visual perception that were not as apparent as items on a screen. *Tactile ways of constructing knowledge* were also legitimated as students manipulated a variety of models, objects, and indeed their own bodies.

In English, written words were a dominant mode both in the sense that they were used most frequently and in the sense that the ability to read or write through this mode tended to be an end goal for the use of other modes. This mode, too, privileges a particular domain of human experience. Jewitt (2006) asserted that the word-by-word, line-by-line nature of this mode presents the world as an unfolding of events over points in time, an affordance that can be powerful in expressive genres such as narratives (Kress, 2003). In this case, however, the concurrent disciplinary goals of aesthetic expression and identity exploration merit a reconsideration of the extensive use of this mode.

The existence of art, music, photography exhibits, video games, and a host of other representations suggests the potential for many modes' ability to provide aesthetic enjoyment and to enrich people's thinking about relationships, identity, emotion, and the human experience—goals that are commensurate with English. Smagorinsky and colleagues (Smagorinsky, Zoss, & O'Donnell-Allen, 2005), for example, worked with a student who preferred non-linear ways of thinking that aligned with his cultural practices. Using line and color to inscribe emotion in a mask was a powerful way for him to instantiate identity. As a second example that points to words' potential to curtail identity expression in English classrooms, the author (Wilson & Boatright, 2011) taught a Native American student who associated written words with colonization and stated he wanted to express himself through grass dancing instead. Similarly, for some English language learners whose identities are intimately tied to home languages (Peirce, 1995), it is important to instantiate curricula wherein writing in English is not the exclusive means through which one is allowed to express identity (Ibrahim, 1999).

At the same time, calls for multimodal English curricula may particularly be difficult to respond to, as was the case of the teachers in this study for whom multimodal representations were easier to integrate into other content areas whose standards did not specify written genres as a primary goal. Chavez, a teacher of English language learners in Southern Arizona, responded to this difficulty by asking her students to make digital podcasts in which they expressed, in one student's words, "things that are important to me" (Wilson, Chavez, & Anders, in press). Through these podcasts—which included music, photographs, illustrations, verbal speech in Spanish and English, and written poetry (often simultaneously)—Chavez's students reflected on and instantiate aspects of identity in ways that included but did not privilege written English. Notably, in this example, rather than using images as a means for understanding *written literature* or images as a way to prompt *writing*, her assignments integrated writing as one among many equally legitimate modes used to communicate identity.

This description of instruction is not to suggest easy solutions for potential problems that teachers might face in integrating multiple modes into English instruction. Instead, this description is intended to highlight the following assertion: If one accepts that different modes "privilege different domains of human experience"—then relying on any one mode in this discipline, whose goal is partially to address "human experience," is perhaps problematic. Teachers can be aware of this tension, including how particular modal configurations may curtail expression for some students, as they consider which modes to use in enacting English curricula while still responding to demands such as standards and assessments.

Representations in mathematics likewise instantiated a particular way of knowing the world. Much has been written (Carraher & Schliemann, 2002; Gutstein, Lipman, Hernandez, & de los Reyes, 2002) about the nature of *abstraction* in this discipline with debate as to what that term means and whether it is a desired goal or the reason why some students dislike mathematics. From a semiotic lens, much of this discipline was instantiated as *abstract* in the sense that it was removed from students' everyday perceptions. For example, unlike earth science, wherein photographs and videos at times showed adults and students conducting experiments together, no image in mathematics showed photographs of people engaged in mathematical activity. With the exception of a photograph of skateboarder Tony Hawk flipping a 360, teachers did not draw students' attention to realistic images as a valid source of information. This lack of realistic images was one indicator that the epistemological grounding of mathematics—its ways of coming to know and express the world—did not include ways of knowing that were grounded in 'the world as it appears' and did not include ways of knowing whose products were visibly constructed by human agents.

Like earth science, mathematics was a "hands-on" discipline in the sense that physical activity was a legitimate means for building, knowing, and expressing knowledge. The two disciplines valued fundamentally different kinds of physical activity, however: In the one, students were moving dirt, their bodies, and clay models whose properties were designed to represent something in the world; whereas in the other, these physical activities included moving colored plastic tiles, spinning geometric images to find the degree of rotational symmetry, and folding nets into three-dimensional shapes. In this latter discipline, body movements (e.g., pointing gestures) were arguably valued primarily for their ability to point out different aspects of these other modes and not as a central source of expressing knowledge in their own right.

Finally, a consideration of numbers and symbols is essential to understanding how mathematics as a discipline instantiated legitimate ways of knowing and expressing the world. The affordances of this mode, which presents the world *by degree* (Lemke, 2003), are many:

This mode enables people to communicate with precision about events in the world as they meet somewhere at a specific time on a specific day, exchange goods, check the temperature, build bridges that can hold a specific weight, and so forth. However, as Rotman (2000) argued, this mode in and of itself limits how the world can be known through removing traces of authorship, including personal markers such as *I believe that* and *I feel that*. Halliday (2006) and colleagues (Halliday & Martin, 1993) have argued that this mode is characterized by a seeming aura of certainty, objectivity, and authority, despite its historical evolution as a human construction and despite its everyday use to make arguments that benefit some people and not others.

To offset the presentation of mathematics as a discipline of certainty, Morgan (1998; 2001) suggested complementing this mode with writing that includes personal pronouns and acknowledges human activity (e.g., I was thinking that…, and then I did this). This book suggests that perhaps another way to provide “grounded mathematics” is through a consideration of the representations that teachers use in addition to the modes that are indispensable for solving problems. It is true that mathematicians may not use photographs in much of their writing in professional journals (Burton & Morgan, 2000). However, politicians, businesspeople, newspaper reporters, documentary makers, and advertisers use numerical representations all of the time—in conjunction with video, music, images, writing, and speech—to prove particular points about global warming, the effectiveness of their products, the harmful policies of the other candidate, and so forth. A consideration of how mathematical arguments are used in these multimodal contexts may help to ground mathematics in representations that acknowledge and parallel a wider variety of human activity more fully than numbers and symbols, shapes, and colored tiles alone.

In sum, this section argues that each discipline, when conceived as a *modal configuration*, is characterized by a collective and related set of affordances and limitations. These affordances and limitations are not exclusively based on modes' physical characteristics in relation to a set of referents. Instead, these affordances and limitations are related to the epistemologies inherent in the modal configurations that are unique to each discipline. Overall, this section recommends leaning toward representational variety in each of the disciplines, not because certain types of representation are authentic to the discipline as reflected in state or national standards, but because individual learners have different ways of knowing and mediating their experiences with the world. According to this logic, multiple modes would enable the expressions of these experiences more fully than limiting a discipline to any one set of modes.

One final point is important to note when considering how the disciplines were instantiated. Three genres—specifically *instructions, multiple choice questions,* and *questions*—were were used with regularity in all classes regardless of content area. In earth science, they comprised 19% of total texts; in English, they comprised 21% of total texts; and in mathematics, they comprised 17% of total texts. It is worth questioning why these genres, comprising about one fifth of texts that the students read in school as a whole, appeared with regularity despite each discipline's differing goals.

Bernstein (2000) maintained that disciplines in schools serve a different purpose from disciplines in the private sector: Namely, he argued, their goal is to regulate and assess students' understandings of knowledge. As defined in this study, instructions are a genre that tells students to do something or instructs them on how to do something, such as *write in response to this prompt,* or *evaluate this expression.* In other words, this genre by definition plays a regulatory role as it seeks to structure students' physical or cognitive actions. *Questions* and *multiple-choice questions* are a similar genre designed to assess students' understandings.

Collectively, these genres served as reminders that the work that students do in school is different from the work of many advanced practitioners. Whereas practitioners can approach relatively open-ended tasks, predetermined instructions and questions drew students' attention to particular concepts that teachers and publishers, as experts, deemed important to learning the discipline. Other texts in school—such as diagrams, numeric/symbolic combinations, and novels—may bear a "family resemblance" to those read by advanced practitioners in each field (Roth, Pozzer-Ardenghi, & Han, 2005), but rarely do professionals answer multiple-choice questions in response to these texts. In this way, certain texts in school positioned young people as *students* whose roles entailed constructing answers and following the directives of those in authority.

The presence of these genres thus underscores another possible tension that teachers may face in enacting curricula in schools. Teachers are not simply teaching earth science, English, or mathematics, but they are teaching these disciplines in a setting wherein they assume the institutional role of teacher and wherein their job entails monitoring students' progress toward disciplinary goals through measures such as grades. Furthermore, as the presence of end-of-year multiple-choice test preparation books in all of the classrooms suggests, students and teachers were also accountable to political and institutional authorities that used multiple-choice tests to measure students' progress. In sum, the presence of these genres indicates that teachers enact curricula in environments that may in some ways proscribe the types of texts they can select.

Developing Metarepresentational Competence

In all, this book suggests that, as students move from classroom to classroom in the course of a regular school day, they can engage in significantly different types of semiotic activity as they read and generate different kinds of representations. While many advocates of disciplinary literacy instruction call for instruction on how different printed (or digital texts) are structured according to disciplinary norms (Klein & Kirkpatrick, 2010; Moje, 2008), this book suggests that these printed texts are only one piece of the puzzle as they are embedded within larger discipline-specific patterns of semiotic activity. For instance, teachers and students may employ gestures and other modes in specific ways that, like these printed texts, are also structured according to the demands of each discipline, and like these printed texts, can be essential means through which a discipline is communicated.

Accordingly, rather than conceptualizing content area literacy instruction as developing cognitive strategies for approaching a set of individual texts, or rather than conceptualizing it as teaching students about how printed texts are structured in accordance with disciplinary norms, this section moves toward a reconceptualization of disciplinary literacy instruction as the active development of metarepresentational competence. This term was coined by DiSessa (2004; cf Greeno & Hall, 1997) who used it to describe how students in mathematics and science can use task-specific parameters (e.g., the need to represent rate) and their knowledge of the purpose of different kinds of representation (e.g., uses for line graphs) to choose representations that will most fully enable them to achieve a particular purpose. DiSessa also used this term to describe how students can be encouraged to generate and explain their own representations even when they have not yet learned standard disciplinary notations.

This chapter reappropriates this term, using it in a way that perhaps moves beyond DiSessa's original intent, to describe students' *metarepresentational competence* as metadiscursive frameworks for understanding how and why one might generate different forms of representation for different purposes within and across disciplines. These frameworks include the ability to critically evaluate how an individual representation meets the standards of the discipline as well as meets one's own goals and preferences as a learner. Finally, this vision of metarepresentational competence includes a strong sense of *representational play* as learners experiment with non-standard forms of communication in conjunction with more standard forms as a means to generating new types of thinking.

The remainder of the chapter will serve to outline this vision of metarepresentational competence, drawing from DiSessa's original five criteria and suggesting how they might be recast to consider students' representational activity across disciplines. To be clear, student data were not analyzed as part of this research, so any recommendations for instruction are speculative and grounded primarily in these five indicators as they are expanded to include a wider range of disciplinary texts. According to DiSessa, metarepresentational competence means that students are able to:

1. Invent or design new representations.
2. Critique and compare the adequacy of representations and judge their suitability for various tasks.
3. Understand the purposes of representations generally and in particular contexts and understand how representations do the work they do for us.
4. Explain representations (e.g., the ability to articulate their competence with the preceding items).

5. Learn new representations quickly and with minimal instruction. (p. 293)

The author then offers two additional criteria for metarepresentational competence:

6. Identify possible effects of resemiotizations, including effects on what is communicated and effects on the experience of the learner.

7. Develop a sense of representational play.

1. Invent or Design New Representations.

At the heart of developing metarepresentational competence is a curriculum wherein students hold a central position as *text designers*. In accordance with this position, students would have frequent opportunities to make decisions regarding how they wanted to build and express their understandings of disciplinary concepts, drawing from semiotic resources they value, including those they may use at home (e.g., the use of spoken Spanish; their knowledge of music; and so forth). Key to this type of curriculum is the question: *How might I represent this?* Students can ask themselves questions such as:

- How can I represent the phases of the moon?
- How can I represent these data showing daily changes in cloud shapes?
- How might I represent the causes and effects of global warming?
- How might I represent my solution to this problem?
- How might I represent unemployment statistics in my community?
- How might I represent Harrison's decision to remove government-issued handicaps?
- How might I represent my position on this issue?

Instead of telling students to make a line graph, draw a diagram, or write a persuasive essay, these types of questions can require students to think more consciously about how they might employ different modes toward different purposes, comparing their responses to their classmates'.

As these examples also suggest, some questions may have the potential to engage students in broader forms of representational practices than others. It would be difficult for students to use music to answer the question, *How might I represent my solution to this problem?* in mathematics. However, when mathematical activity is embedded in larger social issues, such as *How might I represent unemployment statistics in my community?,* more potential arises for different kinds of semiotic activity.

Students might represent the unemployment rate as a pie chart showing the percentage of the currently employed as compared to the currently unemployed; as a line graph showing changes in the unemployment rate over time; as a numeric ratio of unemployed men to unemployed women; as a numeric ratio of unemployed African Americans to unemployed Whites; and more. In this case, music, artistic drawings, or video footage of somebody telling her unemployment story might help students to make an argument about unemployment in ways that embed mathematics in more diverse forms of semiotic activity, with students having more latitude to choose representations that align with their preferences and strengths. Part of teachers' instructional decisions, then, might entail selecting discipline-appropriate issues that can lend themselves to greater semiotic diversity and that would enable students to have wider latitude in choosing types of representation.

2. Critique and compare the adequacy of representations and judge their suitability for various tasks.

Central to this criterion is the concept of affordances and limitations—the idea that although every representation can communicate or accomplish something, there are also some things that it cannot communicate or that it cannot do. In relation to the first question, after students had generated representations, they could then critically discuss their own and others' work, including a evaluation of what representational features were helpful for the task at hand, what features had a powerful effect on them, what features might have been helpful, or what features might have been misleading.

Take the example of lunar phases. In a class wherein semiotic diversity was encouraged, one group of students could represent this concept by revolving an object (the moon) around another object (the earth) while another student held an object representing the sun. Another group might choose to represent lunar phases as a diagram on a poster board. As students shared and evaluated each other's representations, questions for evaluation might include: *How is this representation like lunar phases? How is this representation not like lunar phases? Why did you decide to represent lunar phases like this instead of some other way?* In this way, students can implicitly or explicitly begin to develop evaluative criteria for representations in earth science by understanding that in this discipline, some representations are evaluated based in part on their fidelity to observable phenomena in the world.

Criteria for effective representations in mathematics and English are different than criteria in earth science, but these types of "critique and comparison" meta-discussions can remain the same, explicitly bringing out the criteria for evaluating communication in each discipline. For example, students could share, compare, and evaluate their representations for solving a problem in mathematics, as Tracy's students did in discussing bars of cheese, noting why some representations helped them to *see patterns* more clearly than others through the use of spatial placement, color, grouping, and other features, or why some digital stories seemed *aesthetically moving* due to a student's photographs that cohered with a particular type of music.

According to DiSessa, these types of discussions can help students develop frameworks for understanding different modes' suitability for accomplishing specific tasks (as specified by the goals of specific disciplines).

Although DiSessa has recommended evaluating representations according to their ability to accomplish a particular task, a different evaluative criterion remains, which includes what a mode can afford in relation to a learner who has particular set of interests. It is not always possible for students to select personally relevant modes such as gestures or music to communicate disciplinary content because these modes cannot always get the job done, but it is reasonable for students to ask themselves if some modes or representational features might make a given task more enjoyable and meaningful than others as a criterion for evaluating those modes' affordances.

3. Understand the purposes of representations generally and in particular contexts and understand how representations do the work they do for us.

The English teachers described throughout this book, as part of their focus on forms of language, were good at explicitly teaching how particular written genres—narratives, historical fiction, informational texts, and so forth—were suited to accomplish particular tasks. This third criterion suggests that a similar type of focus on form can be applied across content areas in the sense that students can explicitly discuss the features and uses for genres of multimodal texts. As an example of this kind of instruction, Grace and Tracy's students learned about different kinds of graphs prior to collecting data and representing them as bar graphs, pie charts, or line graphs. Grace's students likewise named reasons why it might be useful to record data in tables prior to making a chart or graph.

In no observed instance, however, did teachers discuss how and why one might use a diagram in science or why one might want to take a photograph or video of something on the earth. Nor was there a discussion in English of why one might want to use music, drama, or graphs to achieve a particular effect on a particular audience. If being able to effectively generate representations for different purposes requires a framework for understanding possible uses for representation, then this study points to places where teachers might consider explicit discussions of how particular modes have been shaped in particular ways (e.g., as diagrams) to accomplish particular kinds of work.

4. Explain representations (e.g., the ability to articulate their competence with the preceding items).

When done in conjunction with the second and third criteria, this fourth criterion can be accomplished through asking students to justify representational decisions. A student who made a diagram in earth science, for example, could identify the genre as a diagram and could explain why he drew particular kinds of arrows and what color meant. One student of English could explain why she chose to combine black and white still photographs on a blog to set a particular tone. A student of mathematics could justify her decision to make a line graph in response to a problem by explaining that a line graph is apt for showing changes over time, while another might justify his decision for drawing an image by grouping objects as he did. In this way, asking students to explain their representational decisions can require them to articulate understandings of why a particular mode or genre is apt for achieving particular purposes.

5. Learn new representations quickly and with minimal instruction.

DiSessa's final criterion is an extension of the first four. This criterion is based on the premise that, when students can articulate what a diagram is, what it might be used for, and what its features often include; when they can articulate that gestures can represent certain things well but might misrepresent other aspects of something; when they can articulate the reasons behind why they might include music in one composition and a numeric table in others; then they can develop frameworks that will help them read and write texts using these modes with increasing proficiency. This skill is especially important in reading many online texts that combine modes for a variety of scientific, mathematical, and aesthetic purposes in creative and unusual ways.

6. Identify possible effects of resemiotizations, including effects on what is communicated and effects on the experience of the learner.

In addition to the first five criteria, the author proposes a sixth criterion essential to developing metarepresentational competence: the explicit acknowledgment that representations are often resemiotized and an awareness of possible effects of those resemiotizations. Iedema (2003) has used the term *resemiotization* to describe what happens when the same 'meaning materials' expressed through one mode are resemiotized and presented through another mode. Specifically, he described how the same 'meaning' that was inscribed in an architectural plan was resemiotized as it was made into a building.

Resemiotization is a regular feature of disciplinary instruction. Students may resemiotize the data from a numeric table by placing it in a graph; students may resemiotize a scene from a novel by presenting it through body movements or as an image; they may resemiotize what they see in the natural world by recording it as a drawing; and more. Kress (2003) uses the term *transduction* to describe what happens to 'meaning materials' when they are resemiotized as another mode, asserting that the meaning materials never remain unchanged. That is, as the physical affordances of the mode changes and as the epistemological commitment expressed by the mode changes, so, too, does the mode's meaning. Thus, what can be expressed through a line graph is fundamentally different than what can be expressed through a table, even though both of them represent the same data points; what can be expressed through a photograph is fundamentally different than what can be expressed through words, even though both of them may represent the same place; and so forth.

As a means toward developing metarepresentational competence, students can discuss different instances in which resemiotization might be beneficial for communicating a certain point. Representing a table as a graph enables people to see change more clearly; representing numeric unemployment statistics as photographs of individual people's faces can be used to achieve a different emotional impact; representing a rock as a clay model can communicate changes over time; representing a personal experience through reading aloud may enable nuance of expression, sound, and inflection more so than a written text; and so forth. The goal of this criterion is for students to ask questions such as *How else might I represent this? What would be the benefits of representing this in a different way?* as they develop an awareness of the various semiotic choices they have available to them, each of which will have different effects on what is communicated.

An explicit discussion of the possible *distortions* caused by resemiotization is also important. In earth science, for example, when a mineral is resemiotized as a photograph, although it still maintains certain properties such as color and crystal structure, it loses properties such as hardness and density which are also essential for understanding the type of mineral. Anscombe's quartet (as found on http://en.wikipedia.org/wiki/Anscombe%27s_quartet and as quoted in Tufte, 1990) is a famous example of how the same line graph can represent fundamentally different data points. In this case, resemiotization by *finding the line of best fit* can lead to misunderstandings of the data. Likewise, resemiotizing qualitative data to quantitative data can also be problematic, as in the case when the phrasing of a survey question shapes the outcome of the results. An explicit acknowledgement of the effects of resemiotization may therefore be an entryway into critical literacy and numeracy instruction by questioning how a text might tell a different story if it were communicated through a different medium and by considering what any representation can convey as well as what it cannot.

Finally, resemiotization is not just important because it shapes what can be communicated through the mode; it is also important because it shapes what is possible for the experience of the learner. Siegel's (1995) concept of *transmediation*, a term she drew from the work of Suhor (1984), suggests that, by translating something into a different mode, students can invent connections between sign systems that lead to enriched understandings. As students ask questions such as *How else might I represent this? What would be the benefits of representing this in a different way?*, then, one criterion for selecting representations can be the effects that a different mode might have on their thinking and on their experience as learners. For instance, the benefit of representing a numeric equation as an image might be that it helps them to reason through a problem, while the benefit of representing an experience as a photograph may be that this medium is a personally meaningful and powerful mode for communication, and so forth.

7. Develop a sense of representational play.

Experimentation with different representational forms has been at the forefront of innovation in every discipline. From authors' experimentation with new forms such as graphic novels or interactive hypertexts; to miners' experimentation with cross-sections as a means to represent layers of the earth; to mathematicians' experimentation with the connections between number and space—new methods of representation have enabled new ways of thinking and new types of activity in each field. This final recommendation for developing metarepresentational competence is a classroom environment characterized by a sense of *representational play* in the sense that teachers actively foster an environment characterized by semiotic diversity wherein non-standard forms are also valued and discussed as potentially useful ways of knowing and communicating the discipline.

Viegas and Wattenburg (2011), leaders of Google's data visualization project, are a harbinger of what representation might be like in digital environments wherein mathematical concepts such as ratio can be communicated through aesthetic methods such as creative shapes (http://hint.fm/); wherein students have opportunities to represent their own and others' writings through visual means such as color and size; and so forth. On their *Many Eyes* website, for example, which includes a link to *Create a Visualization*, students can choose among different visual templates to represent issues that matter to them, featuring examples such as youth homicide rates in Brazil and the rhetoric of speeches by Barack Obama. As this example suggests, representational possibilities are expanding as technology is expanding, and that building a sense of *representational play* can position students at the forefront of this phenomenon by thinking about how they might build and express their mathematical, scientific, and aesthetic understandings of the world in innovative ways in ways that transverse disciplinary boundaries.

Chapter Summary

Because each discipline described in this research sought to represent a different body of content, it was characterized by predictable patterns of representation that collectively held a set of affordances and limitations, which privileged particular domains of human experience. Because diverse learners may each have different ways of knowing and expressing the world, this chapter calls for disciplinary tasks that lend themselves to more semiotic diversity. The chapter concludes with a vision for the development of metarepresentational competence, one that would encourage students to consider how multiple modes for communicating, from embodied representation to graphs, are valid means for expression, each possessing its own affordances and limitations in expressing a particular body of content and in mediating the experience of the learner.

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APPENDIX A

DESCRIPTION OF RESEARCH

For almost a century, researchers and literacy professionals (e.g., Gray, 1925; Herber, 1978; Moje, 2008) have called for explicit literacy instruction in each discipline. Teachers, they maintain, are not just teaching *content;* they are also teaching students how to *read* texts that communicate disciplinary content and to *write* texts that align with the conventions of the discipline. As such, according to this view, every teacher should ideally be a teacher of reading (to quote Gray's now famous mantra) and a teacher of writing.

At the same time, accompanying this decades-old call for more explicit content area literacy instruction has been a concurrent body of research suggesting that many disciplinary teachers are not providing explicit reading and writing instruction (Hall, 2005). Reasons offered for this disconnection are various, ranging from some teachers' beliefs that they are not qualified to teach reading and writing (Bintz, 1997; Yore, 1991), to school climates that are not conducive toward active and critical approaches to texts (O'Brien, Moje, & Stewart, 1995), to other teachers' beliefs that literacy instruction may in fact be peripheral or nonessential to learning disciplinary content (Donahue, 2000; O'Brien & Stewart, 1990), and more.

This book was designed to address another potential reason why disciplinary literacy instruction does not "take" in many secondary classrooms: Recommendations for reading and writing instruction do not often account for the wide range of texts that teachers use in their classrooms, including gestures, manipulatives, and so forth (Wilson, 2010). Although a sizeable body of research has addressed how multiple types of texts are integrated in individual lessons or units (Brenner et al., 1997; Prain & Waldrip, 2006), few studies have documented the general patterns of texts that teachers use over time as their students learn core disciplinary ideas throughout the school year. Under the belief that recommendations for disciplinary literacy instruction should be grounded in the characteristics of disciplinary texts, the overarching purpose of this study was to distinguish patterns of representation used by teachers in ten middle school classrooms representing three academic content areas: earth science, English/language arts, and mathematics.

Theories of social semiotics (e.g., Halliday, 1978; Hodge & Kress, 1988) and multimodality (Kress, 2003; Jewitt, 2006; van Leeuwen, 2005) provided a useful lens through which to pursue this line of inquiry for at least two primary reasons. First, theorists of multimodality assert that written or spoken words are but one type of representation that is by no means superior to other forms of representation in their communicative capacity. Instead, theories of multimodality consider a given representation's *affordances,* under the assertion that certain modes, based on their properties and use in context, are better suited to achieve particular goals or communicate certain concepts. As such, this theory is a useful framework for arguments that *gestures* or *moving images* can be essential texts that students must read to generate in-depth disciplinary understandings, rather than peripheral or decorative add-ons to the "real" texts, the written paragraphs.

Theories of social semiotics were also appropriate to frame this research because, in effect, they put the *discipline* back into *disciplinary literacy instruction.* Social semioticians assert that texts do not occur in a vacuum; instead, they are the product of social groups such as mathematicians, literary analysts, and scientists. These people select, combine, read, exchange, create, and use texts as they participate in their respective academic communities, each of which is characterized by particular sets of goals and values that are grounded in their immediate and distant histories and activities. These values, goals, activities, and histories both shape and are shaped by texts.

A brief example will illustrate this theoretical concept. Geologists' goals have historically included studying the materials that comprise the earth. In accordance with these goals, they developed texts such as cross-sections of soil layers and maps of mineral to communicate aspects of Earth's composition. These visual texts developed due to the goals of practitioners of the discipline; once developed, they became staples used for the communication of many concepts in geology (Rudwick, 1976). Likewise, texts in all disciplines shape and are shaped by the particular concerns, histories, values, and goals of practitioners within this discipline.

This theoretical framework leads to at least two assumptions. First, it assumes that each discipline will be characterized by *specific patterns of representation* that have arisen due to the distinct goals and activities of practitioners within that discipline. This assumption is easily quantifiable: Researchers can count the types of representations used in different content areas (e.g., numbers/symbols, images, gestures) and describe the extent to which each type of representation is prominent in each academic discipline.

Second, this theoretical framework assumes that these observable patterns of representation can be explained based on the demands of the content and problems faced by people working within the discipline. In other words, a social semiotic theoretical framework assumes that people will choose or create a given representation based in part on its ability to help them communicate an idea or reason through a problem. Overall, because people within a discipline are working on a set of related goals and activities, these representations should have a general set of affordances in the sense that they have been shaped to allow people to work on a related set of tasks.

Although this second assumption is not as easily quantifiable as the first, evidence-based inferences can be made about why teachers use predictable patterns of representation as they engage their students in the core problems of their discipline. These inferences are grounded in observations of representations as they are being used, as well as in extant literature on the affordances of representations. For example, one might infer that geologists predictably used maps instead of gestures to communicate locations of mineral deposits due to maps' spatial layout that communicates that *"this* is *there"* at a specific coordinate in relation to other minerals and familiar landmarks. Gestures, which are fleeting and imprecise, do not have the same affordances as maps for somebody who wants to achieve the purpose of locating a mineral deposit that is several miles away.

In accordance with these theories of social semiotics, this book seeks to answer three general questions:

- *What discipline-specific patterns of representation characterized the earth science, English/language arts, and mathematics, instruction of seven middle school teachers?* This book offers answers to this question by providing a frequency count of the types of representation in each discipline and by describing how they were used in practice.
- *What were the affordances of these discipline-specific representations in communicating disciplinary content? In other words, why might the teachers have used these representations and not others? What are the limitations of these types of representation?* This second set of questions is designed to elaborate on the first question by offering inferences about *why* certain patterns of representation are used in each

discipline. Subsets of this question include inquiries such as the following: What are the affordances of a particular mode (e.g., gestures) as students are learning earth science? How do teachers combine different modes in lessons, and what does each mode have to offer that others do not? This book offers possible answers to these questions by connecting the material affordances of texts (e.g., the spatial layout of maps) to what the teachers sought to communicate (e.g., the location of mineral deposits) as determined through the use of multimodal concordance charts, which compare what individual modes have to offer in any given act of communication.

• *When notions of "disciplinary texts" are expanded to encompass multiple forms of representation, what are possible implications for discipline-specific literacy instruction?* To be clear, the research described in this book was not designed to make claims about the effectiveness of certain types of literacy instruction on multimodal texts. Possible answers to this third question draw from theories of social semiotics and existing research on literacy instruction to speculate on how these ideas might be applied to important (but often undervalued) disciplinary texts that were identified in response to question one.

Research Design

Stake (2006) asserted that multiple case study research is useful for exploring a "phenomenon…of which we might seek examples to study" (p. 6). In accordance with the research questions, the intended focal phenomenon in this study was disciplinary representations. Several cases of classroom instruction from three disciplines—earth science, English, and mathematics—were observed over the course of about one school year (eight to nine months) in order to better understand this phenomenon in middle schools.

According to Stake, this focus on a single target necessitates a shift “toward constrained viewing of the cases” (p. 6) as different aspects of the teachers’ instruction (e.g., classroom management techniques) were not considered when they did not contribute to an understanding of disciplinary representations. Stake further elaborated that multiple case study research requires a shift from the question *What helps us understand the case?* toward the question *What helps us understand the phenomenon?* Participant selection, data collection, and data analysis of these cases were planned to build understandings of the phenomenon of *disciplinary representation*.

Participant Selection

Seven middle school teachers in the Southeastern United States were purposively selected (Merriam, 1998) to participate in this study for two reasons. First, they were recognized as effective teachers according to several measures: the recommendations of university professors, administrators, and other secondary teachers who were their colleagues; their high end-of-year test scores as compared to other teachers in their respective districts; and/or their nomination for different awards, including state, district, and regional Teacher of the Year awards and including recognition from national teaching organizations.

Grace and Francine taught in a middle school that had received a national *Title One Distinguished School* designation for its excellence in teaching students from low-income populations. Even while working among a group of dedicated faculty members, Grace and Francine stood out for their reputations as school leaders. Grace, for example, provided professional development for other mathematics teachers and served on the school’s leadership team, while Francine’s colleagues nominated her for Teacher of the Year.

Alice worked at a Title 1 middle school in the same district, leading a popular after-school program at the request of her principal who noted the good rapport she had with her students. Like Alice, Karl worked in a Title 1 middle school that consistently met standards of Adequate Yearly Progress as defined by the federal government. His students were known for unusually high pass rates on the end-of-year tests, an accomplishment that contributed to his principal's decision to remove students who were at risk of failing from their non-tested classes so they could receive additional mathematics instruction in classes with him.

Tracy and Nancy Rae both worked in the same rural district wherein 68% of students received free or reduced lunch, and they, too, were recognized as school leaders. Tracy spearheaded her school's push toward inquiry-based mathematics instruction, while Nancy Rae had won several Teacher of the Year Awards by various sponsors. Annette likewise taught in a rural area. In the town where her school was located, the average median income for a household was $19,917 according to the U.S. Census Bureau. Despite possible disadvantages associated with a lack of resources for schools in her county, the state superintendent had designated Annette's middle school as a statewide School of Excellence in the year prior to data collection, a fact that the town announced proudly on a large bulletin board on its main street. Annette, too, stood out even among a distinguished group according to her colleagues who recommended her as a good candidate for participation in this research based on their belief that she effectively supported her students' disciplinary learning.

In all, the seven teachers shared at least two characteristics in common: the esteem of their colleagues and high end-of-year test scores as compared to other teachers in their district. Although all seven teachers taught in schools whose student populations were considered to have a low income, other demographics varied considerably (See Figures 5.1a and 5.1b). Karl, for example, did not teach any English language learners, whereas Grace, Francine, and Alice taught the highest percentage of English language learners (15% according to a report by their school district). It was hoped that, by studying these particular seven teachers, this research could provide a description of the representations used by people who were known for making demanding disciplinary content accessible to middle school students from varying socioeconomic and ethnic backgrounds.

Along with being selected based on their reputation for excellence, six of the seven teachers were also selected because they taught two content areas and were highly qualified in both. The purpose of this second criterion was to enable particular types of inferences about the characteristics of texts in each discipline. For example, Grace and Tracy both used *pointing* as the most common gesture in mathematics, whereas they both primarily used gestures in earth science to indicate different types of *movement.* Because they both taught two disciplines, it was inferred that these differences in gestures were not exclusively due to idiosyncrasies in the teachers' styles of communication but were due at least in part to the demands of the discipline. Francine, however, unlike the other six teachers, taught only one discipline in a combined reading/language arts block. A colleague of Grace's whom the author met while doing research with her, Francine was selected for inclusion in this study because of her efforts to integrate visual arts into her curricula. It was hoped that Francine would provide a picture of how multiple modes could be used for teaching English.

Data Collection

To study the patterns of representation used across the content area classrooms, four sources of data were collected and coded: *field notes* from classroom observations, *photographs* of texts the teachers used in their classrooms, *video-recordings* of several lessons in each content area, and *interview transcripts* from periodic interviews held with each teacher.

Field notes, the first source of data, were written during observations of between 29 and 95 lessons for each of the seven teachers (Emerson, Fretz, & Shaw, 1995). These field notes focused primarily on describing the types of representations used in the classroom and on students’ and teachers’ conversations around these texts. Discrepancies in the amount of time spent with each teacher were due to a variety of scheduling difficulties. For instance, the teacher who was observed and interviewed the fewest times, Karl, taught on a schedule that rotated daily and that occasionally changed on a day’s notice. *Photographs* of the teachers’ representations served as the second source of data. Whenever students’ attention was drawn toward a text—whether it was a textbook diagram, problems from a multiple-choice test, a quick sketch on the board, a sentence used for grammar correction, a worksheet with numerical problems, a bulleted list, or a lab experiment—these texts were photographed and combined with the written field notes for later analysis.

Six of the teachers selected several lessons or lesson segments (three to six for each teacher in each discipline) to be *videotaped* because they believed these activities were representative of the types of effective instruction they might provide as part of their disciplines. Francine’s instruction was not videotaped because she participated in the study during a different eight-month duration than the other teachers, and the author did not obtain permission to record her classroom. For the remaining six teachers, video recordings of their instruction were first transcribed into written form: Teachers’ and students’ verbal statements were written, and visual representations, such as gestures and diagrams, were described in writing. Images from the videos were then placed beside the written transcriptions as new representations were brought into their lessons.

Each teacher was *interviewed* for 25-60 minutes four to nine times throughout the school year at regular intervals. In accordance with Stake's (2006) assertion that data collection should be geared toward the focal phenomenon, teachers were asked questions regarding why they chose particular types of representation and how effective they believed those representations were in helping students to achieve their instructional objectives. During most of the interviews, the teachers were given several strips of paper, each of which contained a photograph or a label describing one representation they used in a given lesson. Teachers ordered these strips in terms of their utility in helping students reach their daily instructional objectives (with many strips being of equal value, if they chose), explained why they ranked the strips in that way, and described what they hoped each representation had to offer. In the introductory and concluding interviews, the teachers were asked general questions about their instruction but did not order strips (see Appendix B). The author recorded or photographed the teachers' strips and paired these photographs with the written interview transcriptions.

Data Analysis

Phase One. The data were analyzed in two phases. The first phase of analysis sought to answer the first research question, *What discipline-specific patterns of representation characterized the earth science, English/language arts,* and *mathematics instruction of seven middle school teachers?* In contrast to the assertion that themes should emerge from data without preconceived hypotheses, Smagorinsky (2008) has asserted that data analysis often begins with a pre-established research theory, research questions, and possibly ideas for codes that have been used in similar studies. In short, Smagorinsky has asserted that, although researchers must account for themes and patterns that appear in the *data*, these themes can simultaneously account for a priori *theoretical perspectives.* As an example of this type of analysis, Smagorinsky and colleagues (e.g., Smagorinsky, Cook, & Johnson, 2003; Smagorinsky, Gibson, Moore, Bickmore, & Cook, 2004) conducted research on teacher development in which they used a sociocultural theoretical framework to analyze data in terms of *tools, goals,* and *settings.* When he applied these concepts to his research, they were grounded both in observable patterns in the data and in his theoretical framework.

Similarly, this study sought to identify patterns of representation by applying and modifying pre-existing conceptions and categories of *texts* and *representation* to this body of data. For instance, Kress, Jewitt, Ogborn, and Tsatserelis (2001) identified *models* in science classrooms as being three-dimensional representations—such as a plastic likeness of a human circulatory system—that were used to explain scientific concepts. This definition of *model* was modified and applied to the data in this study. Similarly, Kress and van Leeuwen's (2006) division of modes into written words, spoken words, gestures, and images (with subdivisions including drawings and photographs) influenced how representations were defined in the data.

Drawing from these a priori conceptions about representation, the author worked with a colleague to read through randomly-selected field notes and video transcriptions. Both of us were former content area teachers (English and history), held advanced degrees in literacy education, and were reasonably familiar with theories of social semiotics. We jointly developed and refined codes for the types of representation that we observed. (See Appendix C for our list of codes). After we had established and tested our codes on randomly selected data, the author coded the entire data set while her colleague coded 10 percent of the data set by reading the written transcripts from field notes or videos and by observing the accompanying images. We achieved over 85 percent agreement in the codes that we assigned, an indicator that our codes were reliable (Lincoln & Guba, 1985).

Gesture was a special code. Because we noticed gestures being used in different ways, we thought the general designation of *gesture* was not specific enough, and consequently we categorized different types of gestures that were modified from existing classification systems (e.g., McNeill, 1992) and that fit patterns we noticed in the data. If several types of gestures (e.g., pointing and action gestures) were used in one instructional episode, we only counted *one* gesture for that episode in the overall frequency charts represented by Tables 1, 2, and 3. However, to more fully analyze how gestures were used in particular ways, we also coded *types* of gesture (as reported in the bar graphs), only counting one *type* of gesture per instructional episode. For example, if a teacher *pointed* ten times and outlined five *shapes* during one instructional episode, we coded once for *pointing* and once for *shape.* Our attempts to distinguish types of gesture thus explains why the numbers of gestures as reported in the bar graphs are different from the numbers of gestures as reported in the tables.

Prior to coding, the author split the field notes into instructional episodes (Siskin, 1994), which were delineated by (a) a shift to a different instructional activity, often as indicated by the daily agenda written on the board, and often accompanied by the distribution of new materials (such as clay or a handout); and/or (b) a new social configuration in the classroom such as a shift from whole-class instruction to group work. For each instructional episode, a particular type of representation was coded only once. For example, although Alice showed her students a series of cartoon drawings to illustrate popular idioms such as raining cats and dogs, *drawings* were coded only once during that instructional episode.

Moreover, if a type of representation was coded as part of a superordinate category, it was not coded a second time. For example, in one lesson, Grace told her students in the center of the room that they were the sun, and she held up a tilted globe and walked in a circle around the students to illustrate the causes of the seasons. One student shined a flashlight on the globe to show how the light's rays hit parts of the tilted globe either directly or indirectly. Although this activity used a *model* (the globe), an *object* (the flashlight), and *embodied representation* (the students' bodies were the sun that represented a particular position in space relative to the moving globe), we coded it only as a *demonstration* because the teacher manipulated "two or more natural elements, objects, and/or models to demonstrate the effects of the interactions between them."

Because reading and writing instruction in schools have historically been largely conceptualized in terms of written words (Kress, 2003), we decided to further split the data into two overarching categories: (a) forms of texts that were primarily reliant on written words; and (b) forms of texts that were primarily reliant on other types of signs, such as *numbers and symbols*; various types of *images* on flat surfaces; *three-dimensional models*, and so forth. It was hoped that, by splitting the data into these two overarching categories, we would be able to challenge (or at least refine) the idea that written words are at the heart of reading and writing instruction.

The first phase of data analysis was designed to answer the first research question by identifying discipline-specific patterns of representation in quantifiable terms. However, this type of analysis was limited in several ways. First, it considered each type of representation separately, without describing how multiple representations were often combined to produce a synergistic "representational chemistry" (Ainsworth, 2006) that was irreducible to its component parts (Lemke, 1998). Although the findings from this analysis enabled the researchers to make arguments that we considered to be important (e.g., *gestures* were the most common type of representation used in earth science), the first phase of descriptive analysis was also limited in the sense that it did not offer possible explanations as to *why* the patterns of representation might be so.

Phase Two. Consequently, the second phase of data analysis sought a more unified method for analyzing multiple representations in conjunction, offering evidence-based inferences as to the affordances and limitations of individual and combined modes as people sought to communicate disciplinary content. To answer the second question, *What were the affordances and limitations of these discipline-specific representations in communicating disciplinary content?*, three instructional segments from each discipline were analyzed using a modified multimodal concordance chart (Baldry & Thibeault, 2006). These episodes were selected for further analysis because the representations therein were in some ways "typical" based on the findings from Phase One. For example, because *sentences* were the most common type of text in English/language arts, an instructional episode that used *sentences* was selected for further analysis; because *gestures* and *images* were the most common texts in earth science, an instructional episode that used these texts was selected for further analysis; and so on.

Each column of the multimodal concordance chart included a different mode used throughout the instructional episode. (See Figures 5.2, 5.3, and 5.4 for an example from each discipline.). While the columns were organized according to *modes*, the rows were organized according to *phases*, defined as "copatterned semiotic selections that are codeployed in a consistent way over a given stretch of text" (Baldry & Thibeault, 2006, p. 47). For example, if a teacher said "this" in *verbal speech* while *pointing* to a *number*, the three modes (speech, gesture, and number/symbol) were split into one phase (indicated by a new row) because they were co-deployed toward a similar communicative end.

Within each phase, the modes were analyzed individually and collectively as a precursor to understanding their affordances. Multimodal concordance charts often accomplish this goal by explaining the modes in terms of Halliday's (1978) *ideational*, *interpersonal,* and *textual* metafunctions. Halliday maintained that the ideational function of language is function by which language is used to refer to phenomena in the universe and to people's experiences and inferences about those phenomena. In other words, this function relates a *representation* to its *referent*, whether that referent is something intangible such as an *emotion* or an *experience,* or a visible object such as a *moon.* As an example of the ideational function of language, *a light bulb* (representation) signified the *sun* (referent) in phase one in the earth science lesson.

Within each phase, the multimodal concordance chart documented what each mode represented uniquely in relation to a referent. For instance, the light bulb represented the properties of *light* and *shape* of the sun, whereas gestures and spoken words did not refer to this property throughout the instructional episode. By identifying what one mode communicated about a referent that was communicated by no other mode, this analysis of the ideational function of each mode enabled the author to begin to draw inferences about individual modes' unique affordances in terms of communicating a discipline-specific body of referents in response to the second research question.

Along with identifying specific affordances unique to each mode, the chart also indicated redundancies across modes. The term *redundancy* in this case does not imply that one mode was not needed or was less important than other modes; instead, it means that two modes were used to represent the same aspect of the same referent. For instance, in phase two of the earth science lesson, the verbal speech *same height* and the *ball placed along the same plane as the light bulb* both represented the same property of the earth's relationship to the sun: their existence on the same plane. This redundancy makes it possible for text to communicate the target concept without one of the modes—for example, in this case, the text could have communicated the idea of *same height* even if Grace did not verbally tell students the objects were at the same height. This concept of redundancy, or two modes representing the same aspect of the same thing, is important for understanding why multiple modes might exist in a given semiotic resource (e.g., an *illustration* of a setting might appear beside a *written short story* in a literature anthology, which also describes a setting) yet teachers only draw students' attention to *one* of the modes.

Modes' affordances are not exclusively defined in terms of the content that they can represent, however; their affordances can also be related to the types of relationships that they enable their users to establish with others. According to Halliday (1978), people establish relationships, identities, and social positions through each act of communication. In the first phase, for example, Grace establishes herself in the role of *expert* or *teacher* in relation to her students by assuming an explanatory role through her speech. Her pointing and gaze also establish a shared point for communication, indicating that she and her students should both be attending to the light bulb as a focal text.

Analyzing the interpersonal function of modes is also important to understanding how disciplines are instantiated in particular ways. Attending to this function enables inferences about how texts positions students in relation to their teacher and in relation to the content. Rotman (2000) has argued, for instance, that numbers and symbols often remove all traces of a human author, presenting strings of text as *commands* to perform a task (e.g., $SA=2(14)+2(7)+ 2(2)$). This property of some numeric and symbolic combinations may be important for understanding why students may feel "alienated" (Fahseh, 1982; Lemke, 1990) from mathematics as they perform a set of commands from an anonymous author with whom they have no connection.

According to Halliday (1973), the *textual* function of language breathes life into the other two functions by producing a "living message" that is "operationally relevant" (p. 42). It produces a comprehensible message by relating parts of the text to each other, and to the context of communication, in ways that are coherent. In the terms of a multimodal concordance chart, the *textual* function of communication connects different modes to each other within the same phase, and it connects the current phase to previous and forthcoming phases. For instance, in the phase from the mathematics lesson, the color *yellow* serves a textual function by showing students how three parts of the representation on the board relate to each other. The spoken sentence, *Does everybody see why she did the two times fourteen?* also serves a textual function by relating the activity of the previous phases, in which a student explained how she wrote the symbolic notation for surface area, to Grace's forthcoming explanation expressed in the current phase.

An analysis of the textual function of communication enabled inferences about how different modes were held together, expressed as complete semiotic packages, in patterned ways in each discipline. For example, this research argues that *pointing* served an indispensable textual function in mathematics by relating one part of a representation to another in ways that enabled individual acts of communication to be comprehensible. Without pointing, some of the teachers' and students' mathematical discourse would not have made sense as a coherent or "living" message.

By examining what each mode represented (the ideational function), by examining how the modes worked together as a synergistic whole (the textual function), and by examining the type of relationships that established between the teachers and their students or between the students and the content (the interpersonal function), the multimodal concordance chart enabled the author to make inferences about the affordances and limitations of specific modes as a whole, including inferences about how the modes offset and complemented each other to achieve specific communicative goals.

Phase Three. The analysis from phase two was limited in the sense that the author wanted to make inferences about how and why individual modes were used across a whole discipline, yet the multimodal concordance chart only provided a snapshot of how modes were used in a few instances of instruction. Phase three was intended to address this problem by connecting the analyses conducted in phase one and phase two.

In phase one, the data had all been coded and uploaded into NVivo, a type of qualitative data software that allowed for the easy retrieval of data that had been given the same code. When the author called up the discipline of *mathematics,* for example, and typed in *images*, a list of all of the instances that had been coded as *images in mathematics*, including photographs, appeared onscreen. After coding a few instances of images in mathematics in phase two, the author noted certain properties: for example, as indicated in Figure 5.4, the image was used to represent a *shape*, was geared toward *solving a problem,* was accompanied by numbers whose *spatial placement* indicated their relationship to the image, was *not* placed in a *realistic setting*, and so forth. Prior to writing the section about modes in each discipline (e.g., images in mathematics), the author called up the data with that code in NVivo, scanned the resulting photographs and lesson segments, and compared them to her analysis from phase two. In this case, for example, the author found that almost all of the images except five were *not in a realistic setting* and included only essential features for *solving a problem.* Although discrepant cases at times were used for later discussion, the purpose was to find how modes were *commonly* used, and this type of general comparison from the codes in phase one and the analysis in phase two enabled the author to draw evidence-based inferences about how modes were used in a broad sense across the data set from a whole discipline.

Establishing confirmability. After the data had been coded in phase one, the author gave the frequency counts of representations to each teacher and verbally described basic trends in patterns of representation that she noticed while showing them photographs of their instruction. The teachers then commented on how the author's perception of representational trends compared to their own perceptions of representational trends in their teaching, a request that the author introduced by saying: "Disagreement would be helpful." With the exception of Annette, who thought she diagrammed more *sentences*, and Francine, who said that in the current year of her teaching (not the year of the study) she did more *embodied representations,* all teachers said that the patterns of representation in the data matched their own perceptions of their teaching.

Confirmability (Lincoln & Guba, 1985) for the study was further established through "data audits" with the second coder who was familiar with the data set. He randomly selected multimodal concordance charts to read and discuss with the author, selected a mode that was used in a given chart, and reviewed the data for that mode in one discipline with the author as she explained her reasoning from phase three. He confirmed that the inferences she drew about the data set seemed legitimate to him based on his familiarity with the data and his knowledge of social semiotics. As a final method of establishing confirmability, the author also shared and discussed her dissertation chapters with one earth science teacher and one mathematics teacher who believed that the description of their discipline was credible in terms of how the discipline might be taught to middle school students.

Limitations

This research was limited in several ways. With the exception of Francine, who identified herself as biracial with an Asian mother and White father, the other teachers described themselves as White. Research has suggested that modes can vary depending on the culture of the text-maker: Gestures used by people in one region, for example, may be different from gestures used by people elsewhere (Kendon, 1995, 2004b). Although these teachers were considered to be successful at communicating disciplinary concepts to diverse students—many of whose rural backgrounds were different from their own—this study does not enable a discussion of how people with different cultural, geographic, and linguistic backgrounds might have enacted disciplines in culture-specific ways to meet the needs of a particular group of learners. Rather than theorizing modes in terms of *personal culture*, therefore, this study theorizes modes in terms of *disciplinary practices*, which does not account for how people with different cultural practices might have enacted the disciplines described in this study.

This book's view of the disciplines presented a particular cultural slant in at least one other way as well. This book defines and presents disciplines in terms of official standards documents, including those made by the state in which the teachers taught and those offered by national organizations such as the National Science Foundation, the American Association of the Advancement of Science, the National Council of Teachers of English, the National Council of Teachers of Mathematics, the National Research Council, and comparable organizations. These documents arguably present a culturally-specific view of each discipline.

For example, Carraher and Schliemann (2002) researched Brazilian street vendors who did not think in terms of the place-ten numeral system yet still successfully participated in complex financial exchanges. In contrast, the National Research Council (2001) defines facility with the base-ten value system as a central component of mathematical thinking. The decision to describe the disciplines as they relate to official standards documents, rather than describing disciplines as they relate to more local ways of knowing, was pragmatic: Teachers and students are accountable for how well their students perform as defined by these standards documents. However, though this decision was pragmatic, it is still problematic in its limited conceptions of what counts as legitimate semiotic activity in each discipline.

This study was also limited in its focus on *teacher representation* rather than on its focus of *student representation* or *student learning.* Arguably, much of the learning in any discipline can come from small-group discussions as students are generating and discussing representations as a means toward accomplishing a discipline-specific task. These activities interplay with other activities such as whole-class discussions punctuated with teacher explanations. The focus on *teacher representation* throughout this book at times presents much of *learning* as being *teacher-centered:* That is, it describes the modes that *teachers* orchestrate to convey a concept. Though student comments, and at times student representations, are included throughout this book—for example, students' drawings on the whiteboard—the author did not have permission to collect student work or record small-group discussions unless they were directed by a teacher.

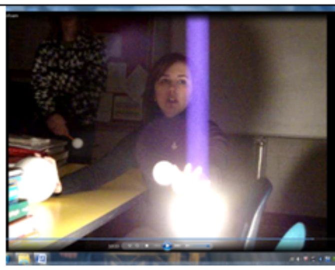
In sum, the lens for this study, although it does not exclude students or student work, is focused primarily on teacher-orchestrated representations without connecting them to student learning outcomes. Though this lens provides a focused view, it is nonetheless a limited view. For this reason, because student learning outcomes were not studied, speculations about implications for instruction are just that: *speculations*. Though grounded in previous research literature and in the characteristics of texts in each discipline, the research design did not enable conclusions about what kinds of reading and writing practices supported students' learning of multimodal texts in ways that might be more effective than others.

Pseudonym	**Years Taught**	**Student Demographics** **(as reported by district/school)**	**Credentials**	**Number of Lessons Observed**
Karl	14: mathematics 1: social studies	• White: 89% • African American: 7% •Asian: 2% • Hispanic: 2%	• BS in middle grades education with mathematics major and social studies minor	29 lessons (70 minutes each)
Alice	11: English 2: social studies	• White: 66% • Black: 13% • Hispanic: 11% • Asian: 6% • Multiracial: 4%	• BS in English education with sociology minor • English as a second language endorsement • reading endorsement • social studies endorsement • MA in English education • Specialist in teaching and learning	66 lessons (50 minutes each)
Tracy	6: mathematics 3: science	• Caucasian: 74% • Hispanic: 13% • African American: 7% • Asian: 5% • Other: 2%	• BA in middle grades education with double major in mathematics and social studies • certified to teach science	66 lessons (50 minutes each)
Francine	3: English 3: reading	• White: 66% • Black: 13% • Hispanic: 11% • Asian: 6% • Multiracial: 4%	• BA in English education • certified to teach reading	51 lessons (90 minutes each)

Figure 5.1a. Description of research participants.

Pseudonym	Years Taught	Student Demographics (as reported by district/school)	Credentials	Number of Lessons Observed
Nancy Rae	16: English 6: science	• White: 80% • Hispanic: 11% • Asian: 4% • Black: 3% • Other: 2%	• BA in middle grades education with a double major in social studies and language arts • MA in middle grades education with an emphasis in science and reading •certified to teach mathematics • gifted endorsement	95 lessons (45 minutes each)
Grace	12: mathematics 6: science	• White: 66% • Black: 13% • Hispanic: 11% • Asian: 6% • Multiracial: 4%	• BA in middle grades education with a double major in mathematics and science • MA in middle grades education with a double major in mathematics and science	49 lessons (90 minutes each)
Annette	21: English 14: social studies	• White: 76% • Black: 20% • Hispanic: 2% • Other: 2%	• BA in elementary education • MA in reading education • Specialist in reading education • certified to teach social studies	46 lessons (70 minutes each)

Figure 5.1b. Description of research participants continued.

Demonstration	Spoken Words	Gesture or Hand Movement	Gaze
 **Analysis:** The light bulb represents the *brightness* or the *light* from sun. This quality of the sun is not represented in other modes, such as gesture or speech, throughout the entire instructional episode. The light bulb alone represents a somewhat spherical *shape*, which is also not represented by any other mode throughout the entire instructional episode.	I have the sun, which is really small here. **Analysis:** The spoken words introduce the representation by signaling that the light bulb represents the *sun.* Grace also draws students' attention to the nature of the representation by noting the *sun* is "really small here," as opposed to how large it should be in comparison to the earth.	Points to light bulb. **Analysis:** This mode is used in conjunction with the word *here* to draw students' attention toward the light bulb, attempting to ensure that students and teacher have a shared point of reference.	Looks at the sun and looks at her students. **Analysis:** This mode is used in conjunction with pointing to draw students' attention toward the sun, but also to establish a direct relationship with students by looking at them.

Textual Function: The gaze, the word *here,* and the pointing gesture work in tandem to draw students' attention toward the *light bulb,* which Grace labels as the *sun* through her verbal narration. In this frame, the light bulb is established as the focal text. Grace's speech and the light bulb both represent the light bulb's *size* as *small* when compared to the Styrofoam ball to the left. However, speech alone is used to clarify that this is an inaccurate aspect of the representation. In this phase, Grace's speech serves an introductory function by naming an object that will be used in this representation.

Ideational Function: The light bulb represents the *sun,* which is an observable physical object. The gesture and the gaze do not represent any object or process in and of themselves, but instead are used to draw students' attention to the light bulb. The words are used to refer to the light bulb by labeling it as the *sun* and noting its relevant properties (in this case, its size).

Interpersonal Function: Grace assumes the role of *expert* and *authority* as she explains a concept to her students who presumably don't know the concept. Throughout the instructional episode, she alone has the right to speak and to use semiotic resources of her choosing, such as the light bulb and Styrofoam ball. Students are standing in a circle around her, establishing her movements and words as the focal text.

*Figure 5.2***.** Sample analysis of one phase of an earth science lesson.

<table>
<tr><th>Image</th><th>Spoken Words</th><th>Gesture or Hand Movement</th><th>Gaze</th></tr>
<tr>
<td>

Analysis: The image depicts a Black soldier carrying a White soldier off of a battlefield with a bloodied knee, intending to contribute to the emotional impact of the story. The image in this phase is the only representation that depicts a potentially important point in the story: The two characters are of different races. The image is a drawing rather than a photograph. The image perhaps cannot be seen well by students at the back of the room at the same distance from Nancy Rae as the camera.</td>
<td>The next thing I remember was collapsing in a heap on the ground and rocking with pain in my leg. Everything started to go black. Then I remembered him pulling me up on his back. I heard him say, "Lord have mercy, child! You're as bad off as I am. I'll tote you. I can't rightly leave you here." I remember being pulled and carried and stumbling. I remember hard branches snapping back in my face and mouths full of dirt as we hit the ground to keep from being seen. I remember slogging through streams, hauling up small bluffs and belly crawling through the dry fields. I remember these things in half-sleep like but I do remember being carried for a powerful long way.

Words such as Lord have mercy child are read in a louder voice with in a more pronounced Southern accent.

Analysis: Speech—in this case, the verbatim reading of written words—is used to tell the story of one friend helping another during the Civil War. The narrator's physical and psychological state are emphasized. Written words cannot be seen by the students.</td>
<td>For the most part, Nancy Rae's hand is in her pocket while the other hand holds the book. She paces around the front of the room. During the reading of hit the ground, she drops shoulders and moves body in a jolting movement.

Analysis: Gestures are used to a minor extent to support the content of the written text.</td>
<td>Eyes are directed toward book with two exceptions: at I'll tote you and hits the ground. In both cases, she turns her head to look at students.

Analysis: The gaze toward the book indicates the book as the focal text. The gaze toward the students re-establishes Nancy Rae's relationship to them.</td>
</tr>
<tr><td colspan="4">Ideational Function: The spoken words (a translation of written words), the image, and the gesture co-represent the narrator's experience in the Civil War as he describes the friend who saved his life. In the next phase, Nancy Rae signals that this story is also supposed to represent the concept of voice.
Textual Function: The teacher's gaze establishes the book as the focal text. Though the gesture, written words, image, and speech work in tandem to represent the author's experience, speech and gesture are the only mode accessible to all students in the sense that they are the only visible modes.
Interpersonal Function: The written words and speech use first-person pronouns to describe an emotional experience also included in the image as one person carries another away from the battlefield in the act of saving his life. Although spatial relationships are indicated in the image, its primary function is to illustrate a particular type of emotional, psychological, or physical experience, as indicated by its co-deployment with the written words and Nancy Rae's speech which frames the lesson in terms of voice.</td></tr>
</table>

Figure 5.3. Sample analysis of one phase of an English lesson.

<table>
<tr><th>Image</th><th>Spoken Words</th><th>Gesture/Hand Movement/Gaze</th><th>Numbers/Symbols</th></tr>
<tr>
<td>

Analysis: The image is a folded-out rectangular prism and is the only representation that indicates *shape,* which is not referred to in words, in numbers, or by gesture in this phase. It is not set in a naturalistic space but on a series of squares intended to make it easier for students to determine each box's surface area by counting the squares. The color yellow is used to highlight two squares, representing the surface area of the front and the back sides of a previously shown box, and to show where these two equal sides appear in the numeric representation of the box's surface area.</td>
<td>Does everybody see why she did the two times fourteen?

If I were to highlight this,

and I did two times 14,

I've got a 14 here

and a 14 there

so that's two of them.

Analysis: Speech is used to refer to the representations on the board, as Grace uses phrases such as *this, here, there,* and *that* to show that her verbal speech is intended as an explanation of the focal text on the board. In the basic phrase "I've got this, and I've got that, so that is two of them"—possible active verbs are eliminated, such as *doubling* or *adding.*</td>
<td>Points to *2(14).*
Gaze is on 2(14).

Clicks on "highlight" button to the right of her board.
Gaze is toward board.

Highlights 14 in yellow.
Gaze is toward highlighted number.

Highlights lower $14m^2$
Gaze is toward highlighted number.

Highlights higher $14m^2$
Gaze is toward highlighted number.

Points to first *2* in numeric expression and taps on it several times.
Gaze is toward students.

Analysis: Grace's pointing and gaze are intended to direct students' attention toward particular aspects of the representation: specifically, the fact that one number in the bottom expression matches with two numbers embedded in the top image.</td>
<td>$SA = 2(14) + 2(7) + 2(2)$

Analysis: The numbers and symbols on the top half of the written representation are tightly integrated with the image by their respective spatial position. For example, the number representing surface area is in the *middle* of the box, the number representing the length of each line is beside that *line* of the box, and so forth.

The numbers at the bottom of the box are not spatially integrated with the numbers/image image on the top half of the representation, but numbers at the bottom are connected to these numbers above through color and pointing.</td>
</tr>
<tr><td colspan="4">**Textual:** Pointing and color served a textual function by showing how specific components of the representation related to each other. The modes are tightly related through a variety of markers: *here, there, this, that* in speech in just one sentence.
Interpersonal: Grace's introductory phrase, *Everybody see why she did the two times fourteen?,* couches the following sentences in terms of a student's explanation in previous phases, placing the student in a position of authority. Grace, too, places herself in a position of authority by explaining the problem on the whiteboard. The numeric/symbolic string at the bottom of the board contains the potential injunction for students to actually find the surface area by multiplying and adding the numbers.
Ideational: The speech seems largely to refer to the representation on the board. As a whole package, the speech, gestures, image, and numbers/symbols are intended to represent *finding the surface area.* The image has eliminated all aspects of the folded-out cracker box she showed students earlier except those designed to help students find the surface area.</td></tr>
</table>

Figure 5.4. Sample analysis of one phase of a mathematics lesson.

APPENDIX B

INTERVIEW QUESTIONS

Initial Interview

1. How long have you taught [subject area]?

2. Would you please describe your teacher certification program that prepared you to teach this subject area?

3. Would you please describe any ongoing professional development seminars you've had that have influenced your teaching in [subject area]?

4. Do you feel more comfortable teaching one subject area more than another? Would you mind explaining why you feel more comfortable teaching that subject area?

5. What are your strengths as a teacher of [subject area]?

6. How do you want to improve as a teacher of [subject area]?

7. What is [subject area]?

8. What do you want students to come away with in [subject area]?

9. In your opinion, what kinds of instructional activities or resources are most useful to students as you are teaching them [subject area]?

10. Please describe a teacher you liked who taught [subject area].

11. Please describe a teacher you disliked who taught [subject area].

12. Is there anything else that is significant for me to know about you as a teacher of [subject area]?

Ongoing Interview Questions
(asked in regards to specific lessons)

1. Would you describe the instructional activity?

2. What was the purpose behind this activity?

3. *Show teachers several different words or photographs, each of which names or shows a type of representation that the teacher used in her or his lessons. For instance, in a mathematics*

lesson, a teacher might receive strips of paper that say: a cylinder (can of baby formula); a drawing of a three-dimensional object; numbers and symbols used to find surface area; written instructions. You used all of these instructional tools as part of this activity. Would you please order these tools in order from most to least important in terms of how they helped students understand the instructional objective? You can rank several or all of the tools as being of equal importance if you'd like.

4. Would you explain why you ranked the instructional tools in this order?

5. What was your reasoning behind using [this particular instructional tool]?

6. What were the strengths of teaching [the targeted concept] in this way?

7. How do you think the activity went?

8. Would do anything differently next time? If so, what?

9. Is there anything else that is important for me to know about your thinking as you planned and implemented this instructional activity?

Final Interview

1. As you reflect over your instruction in [subject area] for the past year, does one lesson or unit stand out to you as being the most effective? What do you think made it effective?

2. Which lesson or unit do you want to change the most? Why? How would you change it?

3. What kinds of resources were most helpful to you in teaching [subject area]?

4. Overall, what are your impressions of yourself as a [subject area] teacher this year? How would you improve? What would you do the same?

Member Check

1. *Review my report on the types of representation I noticed that teachers used in each content area.* How does this description compare to your impressions of your teaching in [subject area]?

2. Why do you think your instruction displayed these patterns of representation in [subject area]?

3. Do you have anything else to say about your teaching in [subject area]?

APPENDIX C

DEFINITIONS OF CODES

Texts Other than Written Words

Coordinate Plane: Measured intervals, often denoted on a flat space with squares of equal size, whose values are indicated along a vertical and horizontal axis.

Demonstration: Teacher-directed manipulation of two or more natural elements, objects, and/or models to demonstrate the effects of the interactions between them.

Diagram: a visual representation designed to explain or portray aspects of a phenomenon, often containing added textual features, such as arrows, lines, or labels, that show causes, processes, or relationships that are difficult to see with the unaided eye.

Drawing: A visual representation drawn to represent something that exists or might exist, including a physically observable entity, an imagined entity, or an emotion.

Embodied Representation: Teachers or students' whole bodies represent another person or an entity in the universe other than themselves.

Geometric Object: A three-dimensional object, often manmade, whose geometric properties (e.g., numbers of faces and vertices) contribute to the learning of the instructional objective.

Geometric Shape: A 2-D or 3-D shape, depicted on a flat surface, comprised of connecting curves or straight lines.

Gesture: Arm/hand movement or gross whole body movement designed to enhance students' understanding of the content, whose intended meaning is usually cued by or complemented by spoken words, excluding gestures contributing to classroom management (such as pointing to a student to call on her or him to give an answer). Subcategories of gestures include the following:

> **Action**: arm/hand/body mimics observable physical acts performed by an organism.
>
> **Distinction**: arm/hand/body is used to separate one concept, category, or observable entity from others.
>
> **Emphasis**: arm/hand/body conveys a visibly strong emotional undertone to the subject under discussion (e.g., banging fist on the table).

Magnitude: arm/hand/body represents a large or small distance, a small or large size, or a small or large amount.

Metaphoric: arm/hand/body represents some aspect of an abstract concept (e.g., putting fingers in a circle to indicate the concept of *whole*).

Movement: arm/hand/body represents an observable entity or entities going from one point to another, with a relative emphasis on (1) direction; (2) speed; or (3) spatial position of the entity's (entities') starting point relative to its (their) ending point.

Pointing: arm/hand/palm/finger is used to draw attention to another form of representation.

Shape: arm/hand/body indicates the physical outline of a form or figure.

Spatial Position: arm/hand/body indicates an observable entity or number placed in a specific location relative to another observable entity or number.

Graph: Bar graph, histogram, line graph, or circle graph that displays relationships among two or more numerical values.

Graphic Organizer: Boxes or circles, connected by lines, which illustrate relationships between ideas.

Lab: Students' manipulation of two or more models, natural elements, or objects to investigate the results of the interaction between them.

Manipulative: An image or item, the movement of which contributes to the instructional objective.

Map: A simplified depiction of a location that highlights the features, such as landforms and cities, of that location.

Measuring Instrument: An implement whose lines or numbers indicate length, capacity, pressure, temperature, or weight.

Model: An object whose properties are designed to resemble something in the world or the solar system, usually on a smaller scale or larger scale.

Moving Images: Video footage, computer-generated graphics, or cartoon animations, any of which are in constant movement on a screen, usually accompanied by verbal narration, speech, sound, or music.

Natural Elements: Trees, rainfall, dirt, the moon, and other phenomena in the physical world that can exist independently of human activity.

Numbers/Symbols: Numerals representing a quantity of something (e.g., 2), oftentimes combined with symbols representing mathematical operations (e.g., +), or symbols representing other concepts (e.g., %, π, l for length, r for radius).

Number Line: A line with points at equally spaced intervals.

Object: A tangible manmade item, often found as a regular part of a classroom setting, whose properties are used to contribute to the instructional objective.

Photograph: A still image of a person or object recorded on film.

Symbols on Existing Text: Lines, arrows, boxes, or other symbols are drawn on pre-existing texts.

Table: An organizational tool that uses headings, rows, and columns to summarize and relate information.

Texts with Written Words

Article: An informational text, four or fewer pages in length, which forms an independent portion of a magazine, website, newspaper, or other publication.

Criteria: Standards by which something should be judged.

Definition: A brief statement that identifies or describes key characteristics of an entity, object, phenomenon, or process.

Essay: A tightly-organized persuasive or expository composition, from one page to several pages in length, which is centered on one controlling idea.

Informational paragraph: A paragraph of one to five sentences in length comprised of descriptions and/or explanations about a single subject. A description is defined as an account of the properties of something, and an explanation is defined as an account of how or why something happens.

Informational book: A book, other than a textbook, whose purpose is to inform the reader about a single subject.

Instructions: Statements describing what to do or how to do an activity or solve a problem.

Label: A word or phrase that names, identifies, or classifies an object, a phenomenon, or a process.

List: A series of words or phrases grouped together because their meanings are in some way related.

Multiple choice question: A question or an incomplete statement accompanied by a series of two to four choices, one of which correctly answers the question or completes the statement.

Narrative: A text that follows a main character or an object through a series of events and ends with a resolution.

Poem: A brief text, often including rhyme, that contains heightened imagery.

Question: A sentence in interrogative form whose purpose is to elicit an answer.

Sentence: A subject and predicate, framed by a period, that is studied for its linguistic properties rather than for the information it gives.

Textbook Section: A subsection of a textbook delineated by one or more subheadings and devoted to a specific subject.

Word: A single word that is studied for its own properties rather than its ability to name something else (e.g., *happy* can be changed to *happily*).

Word Problem: A scenario, one to three sentences in length, which presents a problem that the reader is expected to solve using mathematical operations.