SIXTH GRADERS' ENGAGEMENT WITH PROSE AND GRAPHICS AS THEY READ SCIENCE TEXTS

by

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DEDICATION

To Emma – For the time you gave me, showing me how you engaged with prose and graphics of science texts, when you had such little time in this world.

To my husband, mijn liefde, Rolf van de Kerkhof – Dank u voor uw geduld. Dank u voor uw energie. En dank u voor het zijn mijn steun.

To my children, Sebastiaan, Mark, and "Kleine Drie," and all children – may you enjoy learning about the world through the words and graphics of science.

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CHAPTER 1
INTRODUCTION

The purpose of this research is a better understanding of the ways students engage with prose and graphics when reading and making sense of science texts. Texts play an important role in learning both during the school years and beyond. Each of us must be able to read and comprehend science texts if we are to be informed about medicine, health, or new technologies. We must also read scientific texts in order to make decisions at individual, national, and global levels.

This research supports my overarching goals to make science knowledge accessible to students, and to help students access that knowledge. Studying ways students engage with science texts can lead to avenues to help students use, and learn from, science texts. When students independently access science knowledge, they become informed about the world. They can then make individual, national and global decisions. Students' access to the science in texts allows them to gain what Robert Moses (2001) described as, "economic access" and "full citizenship."

Scientific texts, whether from a book, journal, magazine, newspaper, or website, will typically entail prose (written language in ordinary form) *and* graphics (iconic representations such as diagrams, illustrations, charts, etc.). The graphics may have various roles, from supporting interest and engagement to providing redundant information, to providing relevant yet different information from the prose, etc. Therefore students must become critical readers — not only of the prose but also of the associated graphics — if they are to make meaning from the text and fully access the science information communicated in the text.

This goal accords with national documents that call for students to become "scientifically literate" — that is, to become knowledgeable and critical participants who "engage in social conversation" about science-related social issues (American Association for the Advancement of Science (AAAS), 1990, 1993; National Research

Council (NRC), 1996, 2012). In fact, the National Research Council (NRC) (2012) stated,

> Being a critical consumer of science and the products of engineering, whether as a lay citizen or a practicing scientist or an engineer, also requires the ability to read or view reports about science in the press or on the Internet and to recognize the salient science, identify sources of error and methodological flaws, and distinguish observations from inferences, arguments from explanations, and claims from evidence. All of these are constructs learned from engaging in a critical discourse around texts. (p. 75)

Hand and colleagues (2003), in discussing science literacy, also stressed the importance of language and literacy of science texts. They said, "Science literacy must include the interpretive strategies needed to cope with science text and to evaluate the validity, certainty and credibility of claims embedded in the text" (p. 612). It is therefore important that students learn to use (and to be critical of) scientific texts for their own learning. Yet for students to do so requires them to access information from the multiple representations so often found in science texts.

In order to help readers effectively access scientific information from texts, and to teach them to, "evaluate and interpret the information," we must first better understand the ways students already engage with prose and graphics.

THREE VIGNETTES LEADING TO THIS RESEARCH

Three experiences influenced my goal to research students' reading and engagement with science texts that contain adjunct graphics. Each of these experiences, which I describe as vignettes, highlights different facets of using adjunct graphics when writing and reading science texts.

The first vignette is of my sister, Victoria, and her then sixth grade daughter, Serena.[1] Serena had been studying for a test in her science class about the water cycle, and asked her mom for help. Victoria began to describe the cycle to her daughter, and began to draw a common representation of the water cycle: A hill or mountain beside a body of water (e.g., a lake), and the sun shining in a partly cloudy sky, with arrows illustrating water evaporating from the lake and moving into the sky, condensing into clouds, falling as precipitation on the land, and flowing back to the lake. When Serena

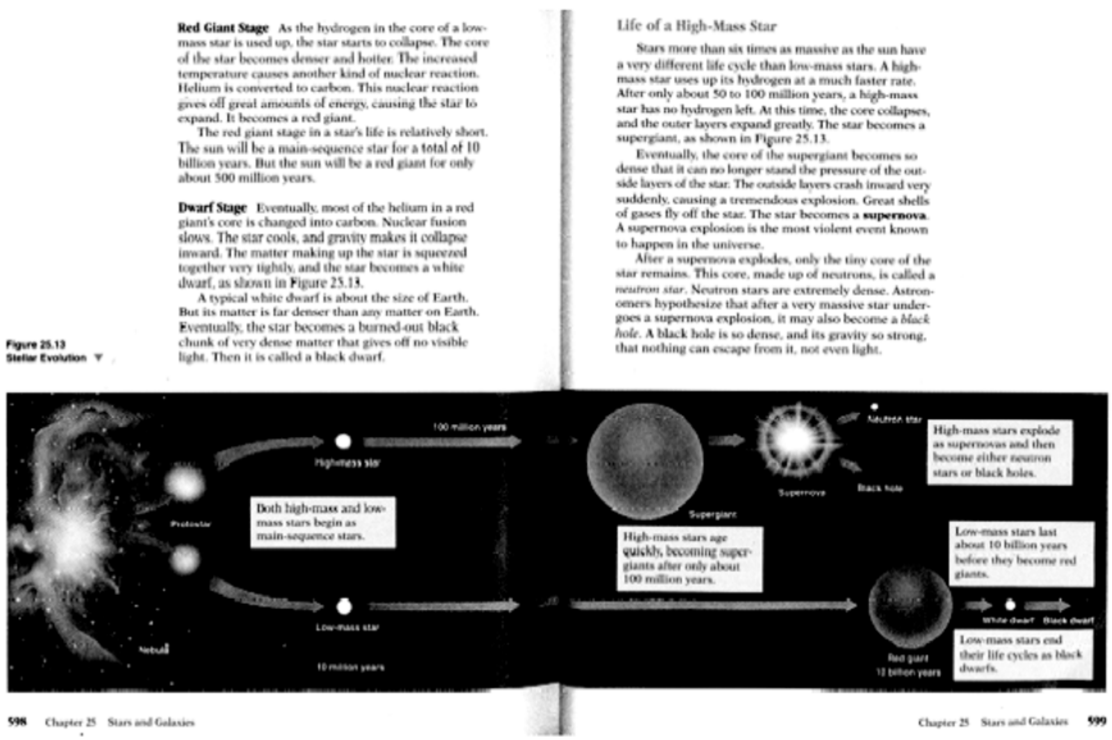
[1] Names of my sister and niece have been changed.

saw what her mom was drawing, she said, “Oh, I think there’s a picture of that in my textbook.” After some more inquiry by Victoria, she learned that Serena had read the text in class and seemed to comprehend it, but that Serena was afraid she did not, “get it completely” and would not remember the content. Serena also mentioned that the teacher did not show the graphic in class. In fact, the teacher neither pointed out graphics like the water cycle, nor did she recreate them in class. After studying the water cycle graphic in the text, Serena felt she understood the concept better and that she could remember it better. Victoria realized that whether or not the teacher focused instruction around the graphic, her daughter was not utilizing the graphic *on her own* to make sense of the science topic. Victoria told me about this incident, and as we talked about it questions formed. We wondered if lack of using of graphics was consistent in Serena’s reading and learning processes, if other students were in the same position, and what ways we (myself, Victoria and the teacher) could help students use the graphics when reading scientific texts in any context.

The second vignette is of myself as a researcher, performing qualitative reading inventories (QRIs) (Leslie & Caldwell, 2000) with seventh graders at a school located in a large urban city. The reading inventory consisted of scientific texts, each rated at different reading levels – from second grade up to high school level. Only the high school level text contained an adjunct graphic. Few students I interviewed had reached the high school level. (In fact, the students in the seventh grade varied from the third grade to high school reading levels). One student who did perform at the designated high school level had read through the text. I then asked him comprehension questions. I noticed that the student looked at the graphic when answering one of the questions. When I asked him why he was looking at the graphic he replied that he was not finding the answer to the question in the prose, so he was looking for the answer in the graphic. I considered his actions a strategy to make more meaning of the text. Again, questions formed as I thought about this student. I wondered if only this student, a proficient reader, would utilize the graphic in such ways or if other, less proficient and even struggling readers might do so as well. I also wondered what I would have observed if the middle-school level text had a graphic.

My questions led me to the third vignette. I decided to look at the middle-school level text used by the QRI, but in its original form (Leslie & Caldwell, 2000). I found that the original text did have a (very salient) adjunct graphic, which was not included in the QRI (Figure 1.1) (DeSpezio, Linner-Luebe, Lisowski, Sparks, & Skoog, 1996). In fact, the graphic related to the prose. It showed the comparison/contrast among the cycle of different stars as described in the prose, and it possibly could have helped students better understand the content in the prose. I wondered: If graphics can support comprehension, then what might the role of graphics be when determining a text's reading level? And, what is the relationship between the role of graphics in texts and assessment a students' reading proficiency? We can only further explore this question when we better understand what students do when reading scientific texts with graphics.

***Figure 1.1.* Text Used for the QRI, Copied from the Original Source (DeSpezio, et al., 1996, p. 598-599)**



Red Giant Stage As the hydrogen in the core of a low-mass star is used up, the star starts to collapse. The core of the star becomes denser and hotter. The increased temperature causes another kind of nuclear reaction. Helium is converted to carbon. This nuclear reaction gives off great amounts of energy, causing the star to expand. It becomes a red giant.

The red giant stage in a star's life is relatively short. The sun will be a main-sequence star for a total of 10 billion years. But the sun will be a red giant for only about 500 million years.

Dwarf Stage Eventually, most of the helium in a red giant's core is changed into carbon. Nuclear fusion slows. The star cools, and gravity makes it collapse inward. The matter making up the star is squeezed together very tightly, and the star becomes a white dwarf, as shown in Figure 25.13.

A typical white dwarf is about the size of Earth. But its matter is far denser than any matter on Earth. Eventually, the star becomes a burned-out black chunk of very dense matter that gives off no visible light. Then it is called a black dwarf.

Life of a High-Mass Star

Stars more than six times as massive as the sun have a very different life cycle than low-mass stars. A high-mass star uses up its hydrogen at a much faster rate. After only about 50 to 100 million years, a high-mass star has no hydrogen left. At this time, the core collapses, and the outer layers expand greatly. The star becomes a supergiant, as shown in Figure 25.13.

Eventually, the core of the supergiant becomes so dense that it can no longer stand the pressure of the outside layers of the star. The outside layers crash inward very suddenly, causing a tremendous explosion. Great shells of gases fly off the star. The star becomes a **supernova**. A supernova explosion is the most violent event known to happen in the universe.

After a supernova explodes, only the tiny core of the star remains. This core, made up of neutrons, is called a *neutron star*. Neutron stars are extremely dense. Astronomers hypothesize that after a very massive star undergoes a supernova explosion, it may also become a *black hole*. A black hole is so dense, and its gravity so strong, that nothing can escape from it, not even light.

Figure 25.13
Stellar Evolution

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As an adult reader, if I were to read the text from the QRI about stars forming, I most definitely would engage with the graphic. In fact, as a chemist reading about newly discovered medicinally active natural products, I commonly looked to graphics to gain more knowledge of the paper. I would usually read the article's abstract and introduction, then analyze the figures and tables, and then skim through the methods section before reading the authors' results and discussion sections. I read in a similar manner when reading texts from the popular press, such as newspaper articles about popular scientific topics that include graphics. I would usually first glance at the graphics, then read the first few paragraphs. I would then look closely at the graphics before deciding if I wanted to continue reading the prose. I could gain the information I need from the texts to make meaning from it and use it in my life. I use the prose *and* graphics in order to do so. In conversation with others I also noticed that there are multiple ways people might engage with prose and graphics in scientific texts.

This study is directed specifically to middle school students as *they* read scientific texts. Students not only read scientific texts in the classroom, but also come across the texts in popular magazines, the Internet, and even find some scientific information in some novels. By better understanding the ways students read and make sense of scientific texts with graphics, we can support them in accessing the scientific information. This leads to my research question.

Research Question: How do students engage with prose and graphics as they read and make sense of science texts?

The research question is an attempt to bridge the fields of literacy, science education and visual-spatial cognition by integrating and building our knowledge of the ways students use graphics and prose when reading science texts. Currently, research in the fields of literacy, science education and visual-spatial cognition do not provide a coherent picture of the ways students engage with the multiple representations in science texts as they read and make sense of the texts. Models of science reading exist, which describe relationships among individual differences, text structure and comprehension processes (Garner, 1990; Garner, Alexander, Gillingham, Kulikowich, & Brown, 1991 Kulikowich, & Brown, 1991; Holliday, Yore, & Alvermann, 1994; Richgels, McGee, Lomax, & Sheard, 1987; Wandersee, 1988; Yore, Craig, & Maguire, 1998). However, few have tested how these models extend and apply to reading texts with prose *and* graphics.

The opposite exists within theories in visual-spatial cognition and science education. These two fields have succeeded in modeling the cognitive processes involved in prose-graphic comprehension, have identified principles of graphics' effectiveness in supporting student learning, and identified relationships between individual differences and comprehension of prose and graphics (Hegarty, Carpenter, & Just, 1991; Mayer, 1997; Moore & Scevak, 1997; Schnotz, 2002). However the fields have focused less on describing students' prose-graphic engagement with respect the many factors that may be involved in their engagement and access to the central ideas in a science text. In fact, in 2010 *Science* dedicated a special section that explored various aspects of literacy in science. However, despite the inclusion of articles that demonstrated the importance of literacy skills in science and strategies to use texts to teach science and support science learning (e.g., Krajcik & Sutherland, 2010; Pearson, Moje, & Greanleaf, 2010; Snow, 2010) there was little explicit attention toward reading texts with graphics.

This study is an attempt to support our understanding of how students engage with and use "visual displays" (graphics) in science texts. More recently Rouet, Lowe and Schnotz (2008) cited Schnotz's (2008) report as a, "very clear demonstration that a full theory of comprehension must take into account the characteristics of the learner, the learning materials and the task, as well as other dimensions of the learning context" (p. 5). The research question addresses these various factors of a reader's engagement that the authors state are needed to contribute to a full theory of comprehension.

Moore and Scevak (1997), members of the few who have questioned and analyzed how students use adjunct graphics when reading texts, also identified the lack of research on how students engage with prose and graphics when reading: "… we would argue there needs to be closer scrutiny of the actual strategies and thought processes that readers engage in when learning in such contexts [from texts and conjointly presented diagrams and tables]" (p. 207). Studying how students use graphics and prose when reading science texts addresses the needs Moore and Scevak identify.

No doubt this research question is expansive. Additionaly, research on comprehension of prose and graphics is not new. As I show in Chapter 2, considerable efforts have focused on graphics' effectiveness, as well as students' individual characteristics in their comprehension of (a) science texts, and of (b) comprehension of graphics. Yet what is new to the topic is my approach to the research question. In this study I answer the question, *How do students engage with prose and graphics as they read and make sense of science texts?* by taking into consideration the underpinnings of a reader's comprehension – that is, the reader, text and context (see the interactive model of reading in Chapter 2). To my knowledge few have focused on the ways students' engagement with the prose and graphics interact with students' characteristics (such as prior knowledge, reading achievement, and interest) and textual characteristics (such as structure, instructional information, interesting information and the informational relationships among the prose and graphics). I did so by using three focal questions:

Focal Question 1: *What patterns emerge with respect to sixth graders overall engagement with prose and graphics while reading and making sense of science texts?* I focused on students' navigations as a way to discern patterns about the ways students engaged with the prose and graphics. I focused on (a) how frequently students looked at and/or referred to the graphics while reading, (b) emerging patterns of students' engagement throughout the reading process and at specific instances, (c) circumstances that may occur when students use, or do not use, the graphics while reading, and (d) students' reasons why they looked to graphics.

Focal Question 2: *How do characteristics of each reader interact with how he/she engages with prose and graphics when reading and making sense of the texts?* This question takes into consideration interactive models of reading, and reflects the importance of reader characteristics. Just as individual characteristics are important for reading texts in general, or of science texts without adjunct graphics, individual characteristics are equally important with additional representations. The characteristics I focused on in this study included prior knowledge, integrated reading achievement and interest.

The texts themselves are also elements in the interactive model of reading, which leads to the third focal question.

Focal Question 3: *How do characteristics of the texts interact with how readers engage with prose and graphics when reading and making sense of the texts?* This question reflects the importance of the text with respect to the ways students engage with and use the text's multiple representations. Almost 20 years ago Schnotz (1993) wrote, "We also do not have much knowledge about how text comprehension interacts with graphic comprehension, and how students integrate verbal and pictorial information" (p.152). To my knowledge this statement could have been repeated in recent years. Research on text characteristics, and the effectiveness of graphics, tends to focus on characteristics of the graphic and the outcome of students' comprehension. And they tend to not with no focus on students' prose-graphic engagement with respect to the affordances and limitations of the texts.

To answer the research and focal questions, I examined sixth graders' reading of chemistry texts. I interviewed students individually. In each interview I asked prior knowledge questions. I asked students to read two texts and to think-aloud as they read. I also asked students to respond to questions about the text (e.g., comprehension, retell) and their engagement with the prose and graphics (e.g., stimulated recall, metacognitive and interest questions). I then used the obtained information to identify certain patterns on students' engagement with prose and graphics with respect to text and student characteristics.

CONTRIBUTION TO THE LITERATURE

This research is a means to bridge research in the fields of literacy, science education and visual-spatial cognition, and to build on knowledge in each field. Also, by better understanding the ways students read and make sense of scientific texts with graphics, we can support students in accessing scientific information.

We can provide the support through various sectors of the science education community. The results of this research can inform curriculum development, as well as any developer of science texts in the popular media. By highlighting characteristics of the texts (such as affordances and limitations of the prose and graphics) that interact with students' characteristics and their engagement with the text (in positive and negative ways), we can build and implement design strategies for science texts.

The results of this research can also inform teachers on ways to attend to prose-graphic integration as a means of providing effective science learning environments

(NRC, 1996, 2012), and what they must do to scaffold readers with varied characteristics (such as struggling and proficient readers).

STRUCTURE OF THIS DISSERTATION

I present my theoretical framework in Chapter 2. I describe the models and studies that have informed my thinking and have provided the basis behind the research questions (e.g., Interactive Models of Reading). In this chapter I also provide a literature review to show how my study fits with and enhances research in the fields of science education, literacy, and visual-spatial cognition.

In Chapter 3 I present methods of the study. This chapter includes methodology and procedures in collecting data (via interviews), analyses of the interviews to reduce data, and analyses of data.

Chapter 4 is a report of students' individual characteristics. In this chapter I determine students' levels of integrated reading achievement, prior knowledge and interest in the texts.

In Chapter 5 I report descriptions of the texts I use in the study as guided by the analytic methods. The two scientific texts, composed of prose and graphics, are the materials I use when I ask students to read. They are also the context with which I ask students a myriad of questions with respect to the research questions. I use the information from Chapters 4 and 5 to present my findings on students' engagement with the texts (Chapter 6).

Chapter 6 discusses answers to the research question and focal questions. In this chapter I identify patterns and relationships pertaining to students' engagement with prose and graphics as they read and make sense of two science texts.

In the final chapter (Chapter 7) I discuss the overall study and implications. I summarize and synthesize findings with respect to four themes that encompass the patterns and relationships identified in Chapter 6. This final chapter also includes recognition of limitations, discussion of how this study can be applied to the science education sector, and ways this study can lead to future endeavors.

CHAPTER 2

THEORETICAL FRAMEWORK & RESEARCH REVIEW

Scientific texts are a tool in science – a means of communicating scientific ideas. I define scientific texts as graphical and verbal representations, expressed through various media (such as paper, computer screens, chalkboards, etc.), which focus on scientific ideas. Scientific texts are a means by which any learner can obtain and use scientific information (The New London Group, 1996).

This definition of scientific texts and my general research question – *How do students engage with prose and graphics as they read and make sense of science texts?* – guide the theoretical framework. In this chapter I link the scientific practice of using representations with a scientifically literate practice of reading (and comprehending) scientific texts.

I first discuss representations in science – form, features and genres of representations, and a graphical representation's conceptual and communicative roles. I then focus on students' use of graphical representations in learning and teaching science, including students' competency in using graphics and their use of prose and graphics in science texts. I then move toward prose and graphics in science texts and discuss models of reading texts and of prose-graphic processing models. The chapter continues with a review of cognitive and metacognitive processes involved in comprehension of science texts, and then a review of factors that interact with students' prose-graphic engagement when reading science texts. (The factors include graphics' effectiveness and individual characteristics.) A discussion of recent reports about instructional design involving graphics follows. I then conclude the chapter with a summary.

REPRESENTATIONS IN SCIENCE

Representations are tools in the culture of science (Latour, 1986). All science fields are ways of thinking about, and ways of exploring, our world and environments. People who do and think science do so with multiple representations – tools such as graphs, data tables, diagrams, mathematical models, pictures, symbols, maps, formulae, written or spoken prose, and gestures.

Multimodal and Multimedia: Forms, Features and Genres of Scientific Representations

Representation of phenomena can be portrayed by many media and modes, and along various scalar dimensions. I can orally describe how atoms can be combined and arranged to make molecules. I can orally describe that these molecules (and the atoms that compose them), under most conditions, are perpetually in motion. I can also use a computer program to depict and animate the translational, rotational and vibrational movements of a molecule, and use the depictions to show how changes in motion relate to temperature. Additionally, I can draw a diagram that shows a person's nose and the particles that move into (and are detected by) the nose.

These examples of communicating the science differ by *media* — the means by which the content is expressed. In fact, representations are employed via various media in science laboratories and in science classrooms. The paper and chalkboard that show written representations are purely visual media, whereas spoken expressions are auditory, and computers can be multimedia, presenting static and dynamic representations as well as auditory input through music and voice (Lemke, 1998). In this study, I focus on students' engagement and use of representations in *visual media* (specifically, expository chemistry texts).

These examples of communicating science also vary by the *modes* with which the content is expressed (e.g., prose and graphics), as well as the *scalar dimensions* of the representations (e.g., macroscopic, symbolic, and molecular perspectives) (Gabel, 1999; Johnstone, 1993, 1997). Many times modes of representation differ in their level of resemblance to the object or idea being represented – from pictures (which closely resemble the actual image of the thing being represented, "the real thing") to graphics (representations that can contain parts which resemble the actual image of the thing being represented, but also contain symbols and conventions of interpretation that make the representation differ from "the real thing").

For the purpose of this study I also organize the many modes of representation into four groups. The first group is motor operations (i.e. gestures), which are not a focus in this study because they are not text-based. The second group is language. Language usually entails written and oral prose. This study focuses on texts. Therefore language in this study only includes *written prose*. The third group includes visual-spatial representations (i.e. graphics, such as diagrams, maps, pictures and graphs). Throughout this dissertation I refer to this third group as *graphics, graphical representations*, or *graphical adjuncts* as a way to make distinct the spatial organization and symbolic meanings that differ from written prose. The fourth group entails mathematical models and functions. Like graphics, mathematical expressions are prominent in science practice.

I also recognize that in text, prose and graphical representations can be less than fully distinct from one another. For example, a data table is mostly verbal, yet the information is presented by a spatial organization different from the left-to-right and top-to-bottom presentation of written prose. A graph also includes words and phrases (language), yet the information is again presented through visual-spatial organization. Other graphics may also include language as captions and/or labels. Even mathematical models include letters, numbers and other symbols found in prose, yet the meanings of these sign systems can be different from prose. However, I organize representations into groups to distinguish prose from "other representations" that are prominent in scientific practice. Distinguishing these three other representation types also allows me to make general statements about the non-prose representations scientists use in texts.

Conceptual and Communicative Roles of Graphical Representations in Science

The multiple graphical representations in every science field have both cognitive and social applications. They provide perceptual accessibility and a means to conceptualize and communicate abstract explanations of the phenomena we experience. For example, chemical concepts help explain much of the complex phenomena that we experience in our everyday lives, yet we use graphics both to conceptualize and to communicate these concepts. Graphical representations have therefore become a form of language – a way that scientists can communicate ideas to others in and out of the scientific communities, as well as a way that scientists can communicate with themselves in order to conceptualize unobservable concepts that explain phenomena (Latour, 1990; Lemke, 1998; McGinn & Roth, 1999; Roth & McGinn, 1998).

Using Graphical Representations to Conceptualize Concepts

Realizing that "our window on the world is very small" (Kozma & Russell, 1997, p. 949), scientists use representations to explain phenomena that are not accessible through direct experiences. Many times phenomena can be too large or too small (in size and/or in time) for us to observe them directly. For example, mathematical models can be used represent what has, is, or will be happening when two stars collide – an event that can span thousands of years.

Other researchers also portray representations as the tools one can use conceptually to connect to the phenomena:

> Graphic displays thus provide physicists with a cognitive and spatial domain to inhabit and wander in. They also transport physical phenomena into the perceptual presence of physicists and serve as a focus in which physicist and physical phenomenon can be brought into physical and symbolic contact with one another. (Ochs, Gonzales, & Jacoby, 1996, p. 350)

This transportation process occurs not only in physics, but all sciences. For example, chemists and biochemists theorize biological mechanisms by using graphical representations of particles – objects only nanometers thick, such as groups of atoms, molecules, proteins, etc. Kozma (2003) also reported ways chemists use representations that closely resembled how I as a chemist used representations in my daily laboratory life. Kozma reported, for example, how a scientist used H^1NMR output data – a representation entailing various peaks that represent substituents of a molecule. I used these representations daily in the laboratory, transforming the information into various other representations of molecules as a way to identify medicinally active components from Peruvian plants.

Using Representations to Communicate Ideas

Although I used the H^1NMR output data representation with my fellow chemists in the laboratory, I also used other translations of the data to report my identification of the bioactive compound to the scientific community. This is one example of graphic use as a form of communication. People communicate by spoken and written words (verbal language), gestures (body language) *and* graphics, especially in science:

> Science is not done, is not communicated, through verbal language alone. It *cannot* be. The "concepts" of science are not verbal concepts, though they have verbal components…To do science, to talk science, to read and write science it is necessary to juggle and combine in canonical ways verbal discourse, mathematical expression, graphical-visual representation, and motor operations in the "natural" (including human-as-natural) world. (Lemke, 1998, p. 3)

In science, graphics can support words and gestures, many times by conveying complex ideas which can be more difficult to communicate by only verbal or body language (such as movement in space and time) (Lemke, 1998). People therefore talk science in multiple representations – prose, gestures and graphics together – to communicate complex knowledge to others. And they do this in the lab, in a classroom, or in texts such as science books and journals.

Graphics are also accepted as part of the scientific discourse through which scientists can effectively and efficiently communicate their observations, data, explanations and models of phenomenon (Latour, 1986; Lynch & Woolgar, 1990). For instance, scientists may apply graphics (such as diagrams, graphs, and equations) to their research papers as a way to provide an organized visual-spatial image of the evidence that bolsters their scientific claim. Many representations have also become widely used only in specific science domains. For example, the ribbon-like structure used to represent a protein can be found in any biochemistry environment, yet may not be found in a physics environment.

USING GRAPHICAL REPRESENTATIONS IN TEACHING AND LEARNING SCIENCE

Graphics are also used in science classrooms as prominent components in scientific discourse and as tools for teaching and learning. For example, chemistry instruction involves using models, diagrams, graphs and visualizations to help students conceptualize phenomenon at the symbolic and molecular levels, and to help students relate these dimensions to their macroscopic observations of chemical reactions (Treagust & Chitleborough, 2001). Chemical representations can provide students with a concrete yet simplified perception of atoms and molecules without delving into the mathematical and physical theories that provide evidence for their existence. It is this same perceptual accessibility that makes modeling a prominent inquiry practice in most science fields (Gilbert & Boutler, 1998). Additionally, the perceptual accessibility of graphical representations makes teachers' use of them a tri-fold process. Graphical representations become instructional tools (McDiarmid, Ball, & Anderson, 1989) to (1) help students conceptualize science ideas and (2) communicate lesson content to students. And, in using the graphics, instructors (3) model a scientific practice. When used as such, Justi and Gilbert (2002) call the representations "teaching models."

Most research on students' use of graphics in science involves such use in the context of the science classroom. However, does an individual need to be able to use various representations in science, even though he or she is not going to be a scientist? I would answer "yes." Both scientific *and* non-scientific communities use multiple representations to exchange ideas and to explain underlying principles of various experiences. Because representations help us communicate and conceptualize ideas in both science communities and "everyday" communities, students should learn how to use and integrate multiple representations as they conceptualize concepts and communicate them to others (McGinn & Roth, 1999). This means that students must become adept at interpreting representations, translating representations into other modes and media, and integrating the representations if they want to further understand science concepts that relate to their world.

Students' Competency in Using Representations

People have an innate ability to represent. They begin using signs and symbols early in their lives (Piaget, 1969; Vygotsky, 1978). The use of signs and symbols in preschool years has been described as a cognitive assimilation of reality (Piaget, 1969). Use of signs and symbols has also been considered a socialization process (Vygotsky, 1978). However, as Vygotsky (1978) wrote, "learning as it occurs in the preschool years differs markedly from school learning, which is concerned with the assimilation of the fundamentals of scientific knowledge" (p. 84). Although students have had practice representing in their childhoods, the purposes of representation change, and students need help navigating the various representational modes, media and scalar dimensions. Indeed, science educators have shown us that students have difficulty using graphical representations, particularly in chemistry (e.g., Ben-Zvi, Eylon, & Silberstein, 1987; Gabel, 1999; Johnstone, 1993; Kozma, 2000; Kozma & Russell, 1997). Students of all ages may have difficulty navigating among chemical representations because they are novices at using the representations, because their understanding of chemical concepts are not yet coherent, and/or because students may have low visual-spatial capabilities (Heitzman, Krajcik, & Davis, 2004; Kozma, 2000; Stieff, Stillings, Arasasingham, Taagepera, & Wamser, 2004; Wu, 2002; Wu, Krajcik, & Soloway, 2001). Also, due to the differences between ways expert chemists and novice chemistry students transfer among and reason about multiple representations, Kozma and Russell (1997) emphasized the importance of chemical educators' support of students' representational competence. The authors describe representational competence (in chemistry) as the ability to "see expressions with different surface features as all representing the same principle, concept, or chemical situation, and … transform the expression of a chemical concept or situation in one form to a different form" (p. 963). Others have continued to study students' competencies in using graphics, especially in chemistry and with respect to multiple representations and static or animated displays (e.g., Stieff, Hegarty, & Deslongchamps, 2011). In fact, diSessa and colleagues (diSessa, 2002, 2004; diSessa, Hammer, & Sherin, 1991; diSessa & Sherin, 2000) have focused on the *native* competencies with representations. By "native," diSessa (2004) means that students' competencies are developed via cultural practices both in and outside the classroom. The authors also coined the term *meta-representational competence* (MRC) to denote students' knowledge about representations and students' capabilities in making and using representations, whether innate or formally taught. diSessa (2002) writes that

> MRC includes, centrally, the ability to design new representations, including both creating representations and judging their adequacy for particular purposes. It also includes understanding how representations work, how to work representations for different purposes, and indeed, what the purposes of representation are. Finally, it is useful also to include within the scope of MRC

> knowledge that allows students to learn to use new representations quickly and the ability to explain representations and their properties. (p. 105)

Students' Use of Prose and Graphics in Science Texts

Students must develop competency in using multiple representations when they learn through first-hand investigations (in-class activities). Yet it is equally important to be competent in using multiple representations, such as prose with graphics, during second-hand investigations as they read, comprehend, and learn from scientific texts (Palincsar, 2001; Palincsar & Magnusson, 1997a, 1997b). My research focuses on such second-hand investigations – that is, how students engage with two modes of representation (prose and graphics) in science texts.

Prose and graphics in scientific texts have been accepted as instructional tools to improve science learning (Carney & Levin, 2002; Mayer, 1994). From a socio-cultural perspective, science learning encompasses knowing which tools (e.g., discursive and representational) are most beneficial in a context, and when and how to use them (Lemke, 1990). Students must not only learn to integrate both the prose and graphics to "learn," but to also take part in the scientific practice of using graphical representations (Lowe, 2000; Roth & Lee, 2004; Roth & McGinn, 1998). As Lowe (2000) stated,

> … it is essential that today's students develop the general visual literacy skills required for dealing with scientific graphics, but they must also learn about particular types of scientific pictures that actually form part of the content of a specific field of scientific or technological study (p. 1).

If graphical representations accompany prose as an instructional tool and as a means for students to participate in scientific practices (Lave & Wenger, 1991), then it is important to understand how students use the graphics when reading scientific texts that incorporate both prose and graphics, what processes students undergo while reading the text, and how they might use the graphics when reading the prose and working to comprehend the entire text.

Understanding students' engagement with prose and graphics in science texts has also become an important topic as technologies increasingly provide easier access to multiple modes of communication and as graphical components have become prominent in both electronic and print-based texts. For example, textbook design has changed through the decades (Bezemer & Gunther, 2009). This change includes more images per page. Bezemer and Kress (2009) reported 0.64 images per page in science textbooks in the 1930s compared to 3.37 images per page in the 2000s. And this change has also occurred not only in science but also in subjects such as English and Mathematics.

This "increasingly visual" (Bezemer & Gunther, 2009, p. 249) organization of information is also prominent outside of the school curriculum, as any genre of science text almost always contains multiple representations of the content (Latour, 1990; Lemke, 1998; Roth, Bowen, & McGinn, 1999). For example, the articles in any science journal, whether it is geared to scientists, as is *Science*; to the layperson, as is *Scientific American*; or even to children, as is the journal *Odyssey*; will usually include some type of graphical representation accompanying written prose. Graphical representations are also prevalent in everyday sources of information such as books, magazines, newspapers, television programs, and websites.

PROSE AND GRAPHICS IN SCIENCE TEXTS

Scientific texts can involve prose independent of graphics (and have done so more frequently in past years, as studies by Bezemer and Gunther (2009) showed). However rarely will one find graphics as the sole representation in a scientific text. Here I first describe scientific texts with respect to the structure of the prose. Then I briefly touch on the roles graphics can play (whether alone or with prose) and the possible relationships between prose and graphics.

Structure of Prose

Prose in any text is structured in particular ways in order to communicate ideas to the reader (Meyer & Freedle, 1984). For example, the prose of scientific texts is usually expository (i.e., informative), and may contain one or more of five different verbal patterns: description (also known as enumeration), sequence, cause/effect, compare/contrast, and problem/solution (Vacca & Vacca, 1993). Very rarely are the patterns used independently. They are usually integrated together, and can even be integrated with patterns of other genres to make hybrid texts (Palincsar, 2001). Science newspaper articles can be hybrid texts, as they can communicate information by expository patterns as well as narrative patterns (such as telling a story and quoting interviewees).

The complexity of multiple verbal patterns makes it more difficult for students to comprehend texts. To identify the structures of prose in any text, the reader must identify the relationships among prepositions and concepts, distinguish important from non-important ideas, and make meaning from these relationships. Therefore, awareness of the structures of prose in scientific texts can positively influence reading comprehension. Yet Cook and Mayer (1988) have shown that even college students had trouble sorting scientific text passages according to the various text patterns. Although sixth graders have some prose structure knowledge (Richgels, et al., 1987), it is likely that they will have the same difficulty as college students, and therefore have difficulty comprehending the text.

Other features of prose in scientific texts, such as vocabulary and subject-area discourses, are also crucial to students' comprehension. Non-awareness of text structure, coupled with lack of vocabulary and inexperience in using scientific discourse, limits students' capacities to understand scientific texts (Holliday, et al., 1994; Moje, et al., 2004). Sixth graders are considered novices to the technical language and scientific discourses used in many science texts. In fact, even texts deemed "considerate" (Armbruster & Anderson, 1985) may still incorporate language, structure, and/or discourse that sixth graders have difficulty comprehending. This lead me to wonder, in such contexts, what ways might a struggling and a proficient reader engage with the text when graphics are present? I attempt to shed light on that question in this study.

Graphics' Roles and Prose-Graphic Relationships in Science Texts

Graphics also can serve one or many functions in scientific texts. Graphics can establish a setting, define and develop characters, develop a plot, provide varied viewpoints, reinforce ideas in the prose and/or add information to make the prose more coherent (Robinson, 2002). Graphics may also motivate readers by supporting emotional and/or cognitive interest (Harp & Mayer, 1997) and promote creativity. The role of graphical adjuncts also includes scaffolding mental processes such as imagery, providing mental models, supporting conceptualization of abstract or non-experienced phenomenon

(Robinson, 2002), expanding the boundaries of working memory (Carpenter & Just, 1989; Hegarty, et al., 1991), and focusing attention toward explanative information in text (Mayer, 1997).

Graphics are commonly situated as comprehension "aids" – that is, one's performance on outcome measures (i.e., comprehension, recall of ideas, etc.) should improve when the graphics are present. This perspective is uni-directional. However, in this study I try to situate the prose and graphics of science texts as representations of science content that are integrative. The text and the information communicated and accessed via the text are dependent upon the information depicted in both the prose and graphics. Therefore prose can "aid" readers to comprehend the graphics and the graphics can "aid" readers to comprehend the prose – this is a bi-directional perspective to comprehending science texts with prose and graphics.

Generally prose and graphics communicate information that can be redundant, complementary, and/or unique with regard to each other. In providing similar and/or different information, each representation can enhance and/or diminish information central to the text. Graphical representation and prose, when conveying unique messages about the same scientific concept, may enhance scientific content (Lemke, 1998). Graphics can also communicate scientific concepts and relationships that may become deconstructed and difficult to conceptualize when described via prose. Similarly, prose can communicate relationships that may be more difficult to portray graphically. In these cases meaning is "multiplied" when all the different representations of a concept are used together (Lemke, 1998). However, students' access to the information in each representation determines whether the meaning is, in fact, "enhanced" and/or "multiplied." Just as science prose might prove difficult to comprehend depending on students' characteristics and the structure and discourses of the prose, so too might graphics be difficult to interpret and comprehend, depending on student characteristics and the structure and systems of the symbols in the graphic.

As shown above (and in the following sections), research commonly focuses on graphics' supportive roles. Yet reports have also discussed how the nature of graphics, as well as the graphics' relation to prose, might contribute to *hindering* comprehension (Garner, Gillingham, & White, 1989; Goldsmith, 1987). Some features of a graphic may be inaccurate, irrelevant, or inconsistent with the subject matter (Roseman, Kesidou, Stern, & Caldwell, 1999). In some cases, a graphic may have "seductive details" – features that not only communicate irrelevant information with respect to the topic of the text, but also lead one's attention away from the major message (Blystone & Dettling, 1990; Sanchez & Wiley, 2006). In other cases, the graphics may be ambiguous, and may lack captions or other visual supports that would resolve the ambiguity (Bowen & Roth, 2002; Mayer & Gallini, 1990). It is in these instances that students' use of graphics may not support their comprehension of the science texts.

MODELS OF READING (SCIENCE) TEXTS AND PROSE-GRAPHIC PROCESSING

Interactive Models of Reading

The RAND Reading Study Group (2002) defined reading comprehension as "the process of simultaneously extracting and constructing meaning through interaction and involvement with written language" (p. 11). In this interactive model of reading, text comprehension occurs with respect to the reader, text, activity, and an overall (sociocultural) context (Figure 2.1). Moje and colleagues (2000) also presented a similar model, specifying reading comprehension as the intersection of the text, reader, *context* (e.g., science class, involving science discourses and content learning) and broader context (Figure 2.2) (Moje, Dillon, & O'Brien, 2000; Tierney & Pearson, 1992).

***Figure 2.1.* Heuristic for Thinking about Reading Comprehension (RAND, 2002, p. 12)**

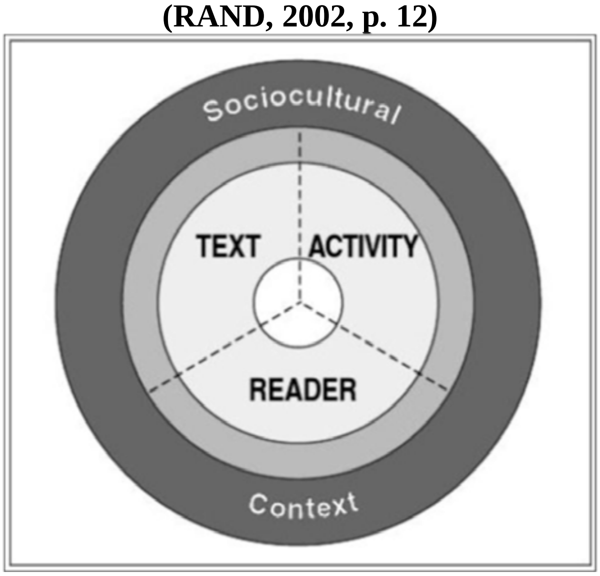
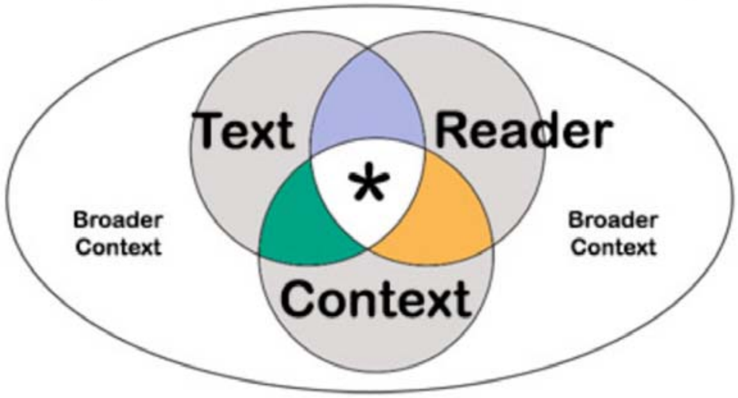


Figure 2.2. **Model of the Reader-Text-Context Interactivity in Reading Comprehension (Moje, Dillon, & O'Brien, 2000)**



Descriptions of the interactive-constructive model of reading have recognized graphics as a component of texts. For example, Holliday and colleagues (1994) described that,

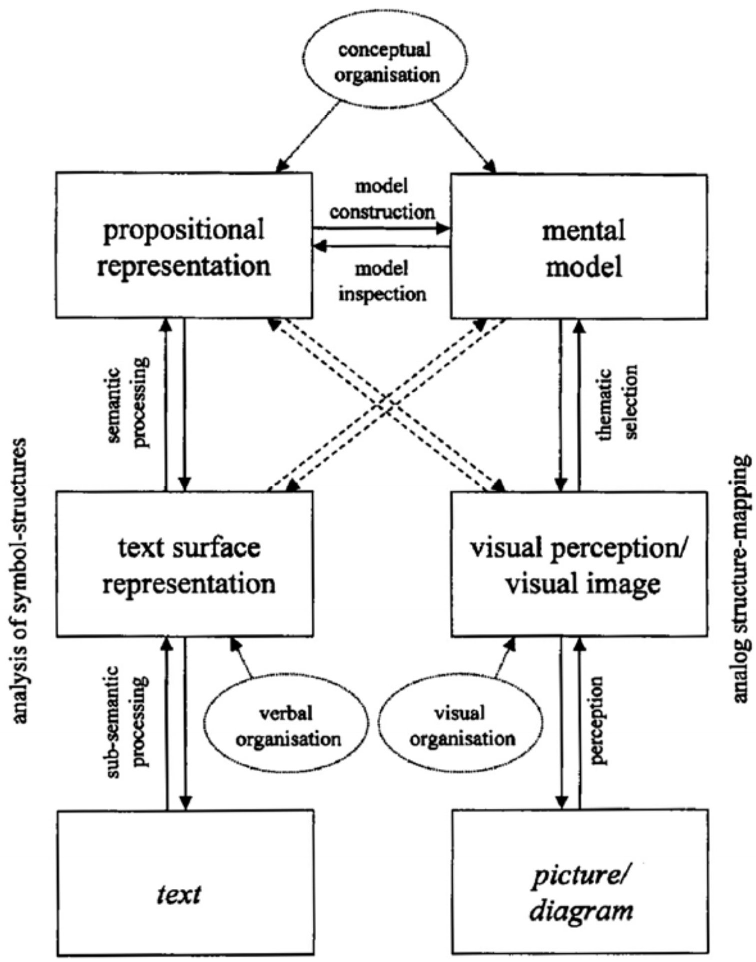
> Readers interactively process information by switching between selective perceptions of text-based information (*print*, *charts*, *pictures*) [italics added] and concurrent experiences (concrete inquiries, discussions, thinking), and comparison of the information and experiences with their personal knowledge (topic, domain, scientific enterprise, textual, strategic). (p. 879)

Yet the interactive model of reading does not further specify how a student is to engage with texts featuring multiple representations. Yore and Shymansky (1991), for example, suggested using graphics for "better comprehension" (p. 35) as 1 of 13 examples of skill-specific activities teachers can do with students in science class, yet did not elaborate on ways to use graphics while comprehending text. This is merely one instance of the interactive model's lack of documentation of student methods for using prose and graphics in reading scientific texts.

Prose-Graphic Processing Models

Alternatively, educational psychology has provided cognitive models to explain ways people process prose and graphics. For example, Figure 2.3 is an integrated model of text and graphic comprehension proposed by Schnotz and Bannert (2002; 2003). This model evolved from Paivio's dual coding theory (viz., Paivio, 1986; Sadoski & Paivio, 2001), Van Dijk and Kintsch's theory of the reading process (viz., Van Dijk & Kintsch, 1983), and an adapted dual coding theory by Mayer (1993; Mayer, 1997).[2]

Figure 2.3. **Integrated Model of Text & Picture Comprehension (Schnotz & Bannert, 2003)**



This model includes a complex interaction in which a reader may activate bottom-up and top-down cognitive schema in order to select task-relevant information and/or organize the information.[3] The model assumes that the modality of information

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[2] For an explanation of how the model differs from those of Paivio and Mayer, see Schnotz et al. (2011)

[3] In the integrated model, comprehension entails descriptive and depictive representations (Figure 2.3). Descriptive representations are the left branch and involve verbal language. These representations include the external (written) prose (called "text" in the model), the internal, mental representation of the structure of prose, and the internal propositional representation. The arrows between these components represent interaction through a reader's sub-semantic, and then semantic, symbol processing. Depictive representations, comprise the right branch. This right branch includes the external graphic (diagrams and pictures, in the model), the internal visual perception of the graphic features, and the internal mental model

conveyed (e.g., pictorial information) may be communicated by that modality or by other modalities (e.g., sound images) (Schnotz, et al., 2011). It also assumes the construction of a single integrated mental model (instead of multiple models or an additive model) (Schnotz, et al., 2011).

Unique to this model is that processing of the representations occurs as one integrated and iterative system after either or both representations are internalized. A reader can process his/her internal visual image into propositions, and/or process the structural representation of prose into a mental model. The reader may also use a previously constructed mental model to build or elaborate upon his/her propositional representation (a top-down process).

This model is problematic, however, in that it is a cognitive model and does not provide connections with the social and context-based dimensions of reading comprehension. Nonetheless, I make use of this model in my study because it shows that even though the prose and graphics are two modes of representation, whether an individual attends to only prose, only graphics, or both, the information he or she processes is integrated into one set of knowledge. The set of knowledge formulated from both representations may be the same as the knowledge formulated with only one of the representations, or it may be more comprehensive. The comprehensiveness depends on the relationship of the representations (i.e., if the information provided by the representations support or interfere with each other) as well as the relationship of the reader to the content. For example, as Schnotz and Bannert (2003) suggest, the integrated model explains two sets of earlier findings: (1) how poor readers benefited (with respect to comprehension and learning) from included graphics and benefited more than good readers; and (2) how "learners with low prior knowledge benefit from pictures in a text, whereas learners with higher prior knowledge seem to be able to construct a mental model of the described content also only from the text (Mayer, 1997)" (p. 154).

However, I still wonder what students *do* while they read science texts with graphics. The integrative model does not assume an individual would attend to both representations equally, but rather shows how an individual may process prose and

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of the content depicted in the graphic. The arrows between these components also represent interaction, in this case through a reader's structure-mapping processing.

graphics together or prose and graphics separately. For example, if a student has difficulty reading a science text, then the model might consist of arrows representing semantic processing, and dotted arrows showing the formation of mental models from text surface representation might be broken. Or these two connections would be shaded more lightly to show that a struggling reader would not be able to perform thoroughly the processes associated with comprehending prose. But does that mean struggling readers would engage with the graphic, or would they use all of their cognitive processing to organize conceptually the little amount of information they could process from the prose? Alternatively, would we observe students using some other strategy as they struggle to comprehend the text? Similar questions can be asked about proficient readers. If students can efficiently process prose into propositions and/or mental models, does this mean the student would not attend to the graphic? These are questions that I touch upon in my study.

Researchers who tended to focus on cognitive models in their studies (i.e., Schnotz and Bannert's (2003) integrative model) have recently recognized the lack of, and need for, the awareness of contextual variables and interactions of those variables in order to understand students' reading and comprehension of multiple representations (Rouet, Lowe, & Schnotz, 2008). Rouet, Lowe and Schnotz clearly described this need in their introduction to *Understanding Multimedia Documents*, where they provided a perspective that closely resembles the interactive models of reading. The authors explained that the typical characterization of comprehension entailed the interaction of the individual and the text, and the individual's construction of a mental representation of the information described in the text. However, the authors state,

> What is missing from this characterization is the awareness that contextual parameters strongly influence both the *availability of text as an information source* [italics added], and the *individual's engagement and control of his or her activity* [italics added].…Our general claim in this volume is that the nature of multimedia comprehension can be properly understood only by articulating these three dimensions into a comprehensive theory. (p. 3, 4)

The three dimensions the authors mention are the individual (i.e., cognitive capacities, prior knowledge, and motivation and purposes), document (i.e. the text – media, sign systems, and modalities), and the context (i.e. tasks, conditions, and support). As the authors mention, we have yet to develop a comprehensive theory of multimedia comprehension that involves these three dimensions.[4] By focusing on students' *engagement with prose and graphics* with regard to the *limitations and affordances of the scientific texts* they read, this dissertation can provide information that Rouet and colleagues suggest is lacking, and thus support a comprehensive theory.

COGNITIVE AND METACOGNITIVE PROCESSES INVOLVED IN COMPREHENDING (SCIENCE) TEXTS WITH PROSE AND GRAPHICS

Cognitive processes involved in comprehending texts – that is, reading comprehension strategies – are important to improving comprehension and learning from text (McNamara, 2007). And successful use of reading strategies is dependent on the reader's metacognition of his or her state of comprehension, whether the text is of solely prose or of prose and graphics. As noted by Schnotz, and colleagues (2011), "Metacognitive processes combined with engagement play a fundamental role in comprehension of text and pictures, as they affect the selection and use of strategies for cognitive processing" (p. 108-109).

Reading Comprehension Strategies for Any Text

What readers do when reading texts (whether with or without graphics) entails use of reading strategies. In fact, the differences in the ways proficient and struggling readers read texts are generally characterized by their awareness and use of reading strategies and reading skills.[5] The phrase *reading strategies* typically refers to actions (such as questioning, summarizing, inferring, etc.) as *tools* students can apply to support their reading and comprehension (Brown, 1985). Reading strategies are "a repertoire of thinking tools," (Palincsar & Schutz, 2011, p. 89) and "deliberate, planful activities undertaken by active learners, many times to remedy perceived cognitive failure" (Garner, 1987, p. 50). Afflerbach and colleagues (2008) also described and defined *reading strategy* in order to clarify the distinction between, and relationship between,

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[4] Here "multimedia" was described as "a combination of verbal and pictorial information as, for example, in texts, realistic pictures, diagrams and graphs, whereby the verbal information can be presented either in visual or the auditory modality" (p. 2). Based on this description, comprehension of texts entailing prose and graphics is included in "multimedia."

[5] In literature proficient and struggling readers have also been described as "good" and "poor" readers and "successful" and "unsuccessful" readers.

reading strategies and *reading skills*. They defined reading strategies as "deliberate, goal-directed attempts to control and modify the readers' efforts to decode text, understand words, and construct meanings of text. The reader's deliberate control, goal-directedness, and awareness define a strategic action" (p. 368). (In contrast, *reading skills* occur automatically and effortlessly, after much practice in using reading and thinking tools.) However, as Graesser (2007) hints, comprehension strategies can be sensitive to the content of, and domain knowledge associated with, the text.

Reading Comprehension Strategies when Texts Include Prose and Graphics

Due to the different representational modes in science texts, descriptions of reading comprehension strategies involve another layer of depth and therefore more complexity. A reader's task of integrating information from multimodal texts includes not only applying ideas communicated in the prose, but also ideas communicated in the graphics.

Readers can perform such cognitive processes – that is, thinking tools such as questioning, summarizing and inferring – on each representation individually. Studies by Cromley and colleagues (2010) and Schlag and Ploetzner (2011) are examples of research that focuses on students' cognitive processes on each representation in the context of reading, and are discussed later. Much research on students' comprehension processes with graphics also illustrated this notion of strategies performed on each representation individually, as the research focused only on the graphics and not on the reading process.

That said, a graphic can in itself be another type of "thinking" tool readers can use to, for example, clarify and infer information in the text. This use of graphics is supported by cognitive science and Hegarty's (2011) review of graphic use. In the review, Hegarty describes how, as external representations, graphics can free working memory and allow other cognitive processes to occur, noting that "In addition to offloading storage, visual displays can allow the offloading of cognitive processes onto perceptual processes (Scaife & Rogers, 1996), referred to by Card et al. (1999) as 'using vision to think'" (p. 450).

Reading Strategies Performed on Each Representation

In 2010, Cromley and colleagues studied college students' reading processes when reading a biology text, separating students' think-aloud comments into verbalizations about prose alone versus verbalizations about the graphics. They then coded and compared the data. The authors found that students tended to make more verbalizations and use more types of cognitive processes with the prose than with the graphics. The authors mentioned that the students seemed to have a "reduced repertoire" (p. 68) of strategies when talking about the diagrams, which suggests that students did not use different sets of strategies with graphics (as compared to the moments when they talked about the prose). Cromley and colleagues also found, however, that students provided more inferences and used more high-level strategies when talking about the graphics than with the prose. And students who made more inferences about the graphics had better post-test measures. Based on this finding, the authors suggest that students who tend to skip or skim over graphics "may be depriving themselves of opportunities to learn science content" (p. 68).

A report by Schlag and Ploetzner (2011) is another example of how reading strategies can be performed on both representations. Schlag and Ploetzner's report focused on processes performed on prose *and* graphics that together make up a *learning strategy*. The authors proposed a learning strategy to help readers learn from prose and graphics. This six-step strategy involves actions, called *learning techniques*, each of which involve both representations. For example, three learning techniques are: "1. *Get an overview*: Shortly read the text and look at the picture in order to get an overview… 2. *Underline relevant terms & label picture elements:* … 3. *Describe*: Summarize in your own words what is represented overall in the text and picture" (p. 928).

Use of Graphics with Reading Strategies

In the literature, descriptions of reading strategies and descriptions of ways proficient readers should read texts seem to take the approach that graphics are tools that can be used to comprehend text. Some literature mentions graphics in descriptions of reading comprehension strategies. For example, Standard 3 from the *Standards for the*

English Language Arts (International Reading Association & National Council of Teachers of English, 1996) states,

> Students apply a wide range of strategies to comprehend, interpret, evaluate, and appreciate texts. They draw on their prior experience, their interactions with other readers and writers, their knowledge of word meaning and of other texts, their word identification strategies, and their understanding of textual features (e.g., sound–letter correspondence, sentence structure, context, *graphics*) [italics added]. (p. 22)

In this and other descriptions, it is assumed that drawing on knowledge of textual features, including graphics, is one available reading strategy. Graphics are therefore features of the text that can be used as a means to perform and/or support other strategies (to draw on knowledge, clarify, extend, construct meaning of the text, etc.). This use of graphics is also a component of reading standards for informational text, especially in the elementary and middle school grades (National Governors Association Center for Best Practices (NGA Center) & Council of Chief State School Officers (CCSSO), 2010). In fact, these guides suggest even first grade students "use illustrations and details in a text to describe its key ideas" (p. 13).

However, little research has focused on how students might actually use graphics to perform and/or support reading strategies. The use of graphics was a primary part of Yore, Craig and Maguire's research on students' science reading processes (viz., Craig & Yore, 1995, 1996; Yore, et al., 1998). Craig and Yore (1995) utilized the following description as an item in their study: "Use visual adjuncts in texts, such as graphs, charts, and photographic reproductions to help clarify, organize, reinforce, enrich, or verify the meanings derived from the text" (p. 230). Yore, Craig and Maguire (1998) also used this description as part of a proposed model of a successful science reader.

Although the authors described a successful reader and used this description in their studies, the studies did not compare and contrast findings with non-successful readers. For example, I wondered if the students in Craig and Yore's (1995) study who did not indicate use of graphics could comprehend the text equally well compared to those who did use the graphics? This dissertation answers similar questions by making comparisons between students' characteristics and their observed and self-reported use of graphics. I specifically describe why (according to the students) they looked at graphics while reading, and compare the students' reasons with individual characteristics.

Hegarty and colleagues (1991) also reported on why individuals might switch between reading prose and inspecting a diagram when reading scientific texts. They concluded that individuals switch among the two modes of representations when 1) the individual has difficulty understanding the information in the prose, 2) the individual is checking a mental representation that he or she made while reading the prose, 3) the individual wants to reactivate information that he or she internalized earlier, and 4) the individual is internalizing information that is not yet communicated in the prose.

These reasons Hegarty and colleagues proposed may possibly compensate for an individual's characteristics (such as prior knowledge and cognitive abilities), or they may compensate for the text. For example, an individual may have difficulty understanding information in the prose because he or she has no prior knowledge of the content, has poor reading skills, and/or because the text structures are unfamiliar. Yet if the strategies are to compensate for certain reader characteristics, then would a successful reader who has no difficulties, or a struggling reader who is not aware of his or her difficulties, perform such strategies? I explore these relationships in this dissertation.

Metacognitive Processes and Awareness of Graphics in Reading

The relationship between readers' knowledge of and use of reading strategies is illustrated by Mokhtari and Reichard (2002), who stated, "…learners must know not only what strategies to use, but also when, where, and how to use them" (p. 250). Based on this description, knowledge of reading strategies has multiple facets. Some of these facets involve knowledge of the strategy itself (e.g., what the strategy is, how it can be used), whereas other facets also incorporate a reader's metacognition. In other words, knowledge about when to use a specific strategy requires recognition of the need for the reading strategy, which would usually occur based on a reader's knowledge of his or her cognition about reading.

Mokhtari and Reichard (2002) showed students' awareness of graphics as a strategy for reading. Their study included one item that pertained to graphic use (of 30 total items). This item was, "I use tables, figures, and pictures in text to increase my understanding." Factor analysis placed this item under a factor the authors called *global reading strategies* – "generalized, intentional reading strategies aimed at setting the stage for the reading act (e.g., setting purpose for reading, making predictions)" (p. 252). As this study was not aimed at understanding students' graphical use, the question of why this item fell under this group (and not the other two identified factors – problem solving and/or support reading) was not discussed.

In researching students' science reading processes, Craig and Yore (1995) reported that graphical use seemed to be a component of students' *knowledge* about science texts, science concepts, and science reading strategies. Specifically, they showed that students' responses to interviews revealed *strategic awareness* by providing the exemplar comment, " 'You look at the pictures to help you understand the words and what is happening in the paragraph'" (p. 202). They used this exemplar to show how the students "indicated that their use of reading strategies is purposeful and the purposes are to aid in figuring out words and sentences, learning, remembering, or understanding" (p. 201-202).

Craig and Yore (1996) also described fourth to eighth grade students' self-reports of their reading processes, indicating that students were aware of the *function* of graphics. In that study, 83% of the 52 students indicated they referred to graphics to help them understand a science text. Also, 60% of those students reported using the graphics after reading, but not while problem solving as they read. The authors called this type of knowledge – knowledge of the roles and functions of graphics in the context of reading science texts – *metagraphical awareness*.

Hegarty (2011) also discussed a reader's "decision" to engage (and the ways he or she engages) with graphics, taking into consideration the reader's meta-knowledge of the graphic and the task:

> The decision to interact, and choice of how to interact with the graphic depends on meta-knowledge of the affordances of that type of display, such as whether it can be zoomed, rotated, or animated. It also depends on meta-knowledge of which interactions with the display are task relevant. This type of understanding has been referred to as meta-representational competence (DiSessa, 2004) and cannot always be assumed. (p. 454)

Recall earlier in this chapter that I discussed diSessa and colleagues' focus on students' competence about their knowledge of graphical representations – that is, students' *meta-representational competence* (MRC) (diSessa, 2002, 2004; diSessa, et al., 1991; diSessa & Sherin, 2000). Meta-representation has indeed become an established term in math and science education.[6] diSessa and Sherin (2000) explained that *meta* in *meta-representation* refers to "…whatever students know *about* representation…" (p. 386). Meta-representation, then, is not unlike Craig and Yore's (1995) metagraphical awareness. However, meta-representation and meta-representational competence have only been discussed in the context of the science classroom, and not in the context of reading scientific texts. On the other hand, *metagraphical awareness* is the awareness of graphics' roles and functions as one *reads the texts* (in the context of reading science texts with graphics). One's metagraphical awareness may be considered as a facet of meta-representation specifically in the context of reading. In this way, as students demonstrate metagraphical awareness, they may also be demonstrating their meta-representational competence in the context of reading scientific texts. Few have focused on students' "native" awareness of graphics with respect to reading scientific texts. This dissertation can add to our knowledge about middle school students' meta-representational competence.

A Review of Factors that may Interact with Students' Prose-Graphic Engagement when Reading Science Texts

Studying students' comprehension of texts that involve prose and graphics is not new. A plethora of studies have focused on either identifying the effectiveness of graphics or the interactions of graphic comprehension with reader characteristics (such as developmental differences, reading ability, spatial and verbal abilities, prior knowledge, and interest and motivation). Most studies included here tended to apply cognitive theories (e.g., Pavio's dual coding theory, or Schnotz and Bannert's (2003) integrative model). These studies have provided knowledge about ways students may process and ultimately comprehend texts with prose and graphics. However, most of the studies with such foci tended to overlook students' actual engagement with the text and instead focused solely on outcome measures. Because of this, few have identified characteristics

[6] In cognitive and developmental psychology, the term *meta-representation* is used synonymously with *theory of mind*, and commonly refers to representation of one's mental representation. The medium of that representation (e.g. a mental representation or an external representation) is defined by context and/or the task at hand. Yet in this study, and in reports by diSessa and colleagues, meta-representation involves representation in the external sense. In fact, diSessa and Sherin (2000) specify that *meta* in *meta-representation* is not used in connection to meta-cognition.

of students' prose-graphic engagement in science texts with respect to students' characteristics as well as affordances and limitations of the texts.

Effectiveness of Graphics

Many scholars have indeed focused on a *graphic's* effectiveness, usually by reporting how varied features of the text (such as absence/presence of a graphic, or placement of a graphic) might help or hinder individuals' recall and/or comprehension. The most common studies on "effectiveness" compared student's performances in reading a text with versus without an adjunct graphic, and sometimes compared performances with reading solely the graphic. These studies were performed as early as the 1970s, and continue today, especially as the modes and media for graphics have developed. For example, Holliday (1976) compared students' performance on a verbal test of comprehension based on whether the students studied nitrogen, water, oxygen and carbon dioxide cycles from solely prose, prose with accompanying flow diagrams of the cycles, or the flow diagrams alone. This comparison showed that students who studied the flow diagrams alone performed best on the verbal test, and no difference occurred between students who studied via prose alone and those who used prose and diagrams. Holliday reasoned that students who studied from both the prose and diagrams most likely focused on the prose sections and did not take advantage of the multiple forms of information. Holliday used the notion of the individuals' processing of the prose and graphics to explain the results, yet did not further pursue readers' processes.

Other studies about the effectiveness of graphics also incorporated analyses of how the relationship of prose and adjunct graphics might help or hinder students, such as the graphics' ability to amend the prose (or vice versa), task interference (Kirby, 1993), and contiguity effects (Mayer, 1997). In fact, Mayer specifically considered individual characteristics when studying how features and placement of graphics help students. He demonstrated that the proximity of prose and adjunct graphics can help students – especially those of *low-prior knowledge* students (versus high prior knowledge students) and those students with *high spatial ability* (versus low spatial ability) (Mayer & Gallini, 1990; Mayer & Sims, 1994).

McTigue (2009) also studied whether adjunct graphics would improve sixth grade students' reading comprehension of two texts (one about a bacteria's life cycle and another about the transformation of energy in a steam-turbine engine). McTigue compared comprehension of students who read a text with an adjunct graphic versus students who read the text without a graphic. She found that comprehension "improved" with inclusion of the graphic in the text about the bacteria's life cycle. However, McTigue identified no improvement for inclusion of a graphic in the text about the engine. In her conclusion, the author emphasized that not all graphics may support students' comprehension of science texts and challenged the generalizability of Mayer's (2001) principles of multimedia design in middle-school settings.

Researchers have also focused on effectiveness of static and animated graphics, usually to determine which is better for learning (Schnotz & Lowe, 2008). However, as Schnotz and Lowe (2008) suggest, a focus on the differences between animated and static graphics is unhelpful, especially because the differences are difficult to distinguish from a psychological perspective. They therefore focus on the commonalities of static and animated graphics, and in doing so, emphasize other factors of the representations' effectiveness:

> The educational effectiveness of an animation depends on the same fundamental set of human information processing capacities that applies in the case of static pictures. Accordingly, the most crucial determinants of effectiveness for both animated and static graphics are *specific details of the way a depiction is designed and used* [italics added] (p. 349).

I italicize the last section of the quote because it most relates to this study. In this dissertation I describe the features of the prose and graphics in each of two texts (i.e., their design), and how these features interact with how readers *engage* with the texts (i.e., how the representations are used).

Individual Differences and Reader Characteristics

A student's characteristics can affect his or her processing strategies and ultimately comprehension. This is well known in both reading research and research on graphic comprehension. Focus on students' individual characteristics is also abundant in research regarding prose (whether it be paragraphs or captions) and graphics together.

Repeatedly, research has reported that the ability for a reader to learn from the integration of prose and adjunct graphics depends on the relationship of the reader –his or her prior knowledge and cognitive abilities – and the task demands of the text (e.g., Hegarty, et al., 1991; Mayer & Gallini, 1990; Schnotz, 2002). As with any task, whether physical or mental, an individual's performance of the task depends on his or her physical and/or cognitive capabilities. In motivation theories on education, learning may not occur as successfully if the task does not match the capabilities of the individual (Eccles, Wigfield, & Schiefele, 1998; Pintrich & Schunk, 2002). This is also true when using graphics: "Visual-spatial text adjuncts and other forms of visual displays can support communication, thinking, and learning only if they interact appropriately with the individual's cognitive system" (Schnotz, 2002, p. 113). Others have also suggested similar ideas, arguing that individuals' logical thinking abilities (Berg & Phillips, 1994), as well as their information processing capacities while reading text (such as the amount of information they can store in working memory while reading) (Carpenter & Just, 1989; Hegarty, et al., 1991), can affect how they integrate prose and graphical representations. In other words, if students' cognitive abilities differ, then the processes they use to comprehend texts with prose and graphics may also differ with respect to those cognitive abilities.

Common individual characteristics that have been recognized as influential to students' processes and comprehension include developmental differences, reading ability, spatial ability, verbal ability, prior knowledge, and motivational differences. These individual characteristics are discussed below. Most studies involved the relationship of students' characteristics to their comprehension and/or recall of texts involving prose and graphics. In these studies the students' characteristics were the independent variable, and the outcome of whether or not students comprehended, or the extent of remembering details, was the dependent variable. Few of these studies focused on the mechanism of reading. Additionally, most of the studies have been performed within cognitive constructs, with little emphasis on the social and cultural situatedness of visual representations.

Prior knowledge

Prior knowledge is a well-known factor in readers' comprehension of any text, especially of technical texts (Graesser, 2007). Prior knowledge comes into play with readers' comprehension of the science topic, including the science ideas and technical terms, as well as readers' comprehension of scientific graphics.

The role of prior knowledge in using multiple representations has commonly been shown via studies on ways novices versus experts use the representations. For example, Kozma and Russell (1997) compared the ways experts and novices responded to various representations. The authors found that novices grouped various representations in different ways than experts, and that the reasons experts provided for the ways they grouped the representations were more conceptually based, whereas the novices tended to base their groups on surface features. The authors also noted that the experts were better than novices in transforming a representation into different but equivalent representations.

Researchers have also compared what expert and novice physicists deem important as they try to comprehend physics tests. Novices selected definitions in the form of prose as important, whereas experts preferred equational definitions (Alexander & Kulikowich, 1994). In this case, the experts could readily apply their prior knowledge to the prose and graphic, and may already have had both propositional and mental models, such that it was more helpful for them to use the equational definitions than prose. However, the novices preferred prose, possibly because the conventions of prose may have been easier to use than the conventions of equations when forming their propositional and mental models of the content.

A study by Hegarty and Justi (1989) also revealed that when reading longer text that described the relationship among components of a pulley system, people who had more domain knowledge about mechanical systems were able to use their prior knowledge and the information in the prose to obtain the information they needed *without referring* to the diagram. However, the researchers also found that when reading shorter text the readers with more domain knowledge spent *more time* examining the diagram. The authors speculated that the excess time on the diagram was due to the readers extracting information from the diagram that was not communicated in the prose.

As well, a recent study by Canham and Hegarty (2010) showed that (prior) knowledge can affect the ways an individual accesses information from complex graphics. The authors found that students spent more time looking at task-relevant information on weather maps after instruction (as compared to before instruction) and performed better in making inferences from the maps. Although Canham and Hegarty focused only on comprehension of graphics, the findings can be applied to students' reading of science texts with prose and graphics. For example, I earlier mentioned Cromley and colleagues' (2010) findings that biology students made more inferences and used more high-level strategies when talking about the graphics versus the prose. Perhaps they could make the high-level inferences due to their prior knowledge (i.e. they were biology students reading about cells' parts and microscopic processes), or even due to the knowledge gained by reading certain parts of the prose and integrating the information with and/or applying the information to the graphics.

My research questions focus on sixth graders' readings about molecules. Generally students have had little, if any, formal instruction about the particulate nature of matter before sixth grade. The students in this study were just beginning a unit on the science topic. I wondered in what ways, in the context of reading, such readers might use graphics when they have some knowledge (varied in completeness and cohesiveness) about molecules and the associated conventional representations. This is a question I address in my study.

Developmental differences

Scholars have looked at the integration of prose and graphics based on a developmental perspective. In the early 1980s researchers looked at whether graphical representations help students differently based on grade level and found mixed results (Winn, 1987). Winn referenced a study by Koran and Koran (1980), who provided evidence that diagrams helped grade 7 students but not grade 8. He also referenced a study by Holliday (1976) that showed diagrams not helping students in grade 10. I also discussed earlier how Moore and Scevak (1997) reported developmental differences with respect to students' reading of science texts that involved tree diagrams. Moore and Scevak noted that a comparison among fifth, seventh and ninth graders' think-aloud comments showed the "older" ninth graders used more strategies than the younger students, including, "explicit linking of text and diagrammatic information…" which was

> … not readily utilized by the younger students and this is particularly evident in the science materials, where even the Grade 7 students placed little emphasis on the relationship between the diagram main ideas and the text main ideas. (p. 219)

This finding, that even the later grades do not seem to integrate the prose and graphics, may mean that there are genres and structures of scientific texts that students in elementary and middle school grades struggle to comprehend (Hubbuch, 1989). The authors also suggested possible factors that led to the developmental differences, such as prior knowledge and visual/verbal preferences. The findings, however, made me wonder if the differences Moore and Scevak (1997) reported were not because of grade level, but a reflection of practice –that students in higher grades may have more experience with, may have developed more strategies for, reading science texts. Indeed, the authors' instructional implications seem to suggest the notion of practice, as they identified, "a rather critical role for explicit teaching of strategies to enhance meaningful links between texts and aids" (p. 220).

Reading ability

Skilled readers "use learning strategies, such as planning, hypothesizing, and rereading, *to coordinate printed verbal and visual displays* [italics added] while reorganizing and reinspecting printed materials with clear goals in mind" (Garner, 1990, p. 881). This would suggest that proficient readers would integrate prose and graphics while reading. However, a different story has emerged in research with proficient and struggling readers. Struggling readers seem to look at graphics more readily while reading. For example, Rusted & Coltheart (1979) analyzed ways proficient and struggling fourth grade readers used pictures when reading prose about animals. They reported that proficient readers spent time on pictures before reading, yet rarely looked at them during reading. On the contrary, struggling readers frequently moved back and forth between prose and pictures. Kozma (1991) suggested that perhaps these results occurred because struggling readers used the pictures to support their decoding of words and to help them build their mental models, whereas proficient readers used the pictures to initiate a schema about animals that supported their reading and comprehension of the text. Possibly struggling students pay more attention to graphics because they lack comprehension of the prose, whereas more proficient students are better at deriving the information from prose alone, and therefore do not need to use the accompanying graphics. This would suggest that a reader who comprehends the prose might not engage with the graphics. It also calls into question when and to what extent proficient readers might integrate the representations while reading.

In another study, Carney & Levin (2002) identified that students looked at adjunct graphical representations *more frequently* when the difficulty of learning content from text *increased*. Although this study focused on the students learning from a difficult text, it also characterizes what any struggling reader might do when challenged to learn from a text difficult *to them*. This finding seems to be in agreement with Palincsar, Dalton and Magnuson (2005), who also found that struggling readers looked more frequently to a graphic compared to proficient readers when reading a science text about light.

Based on any of these studies, one might come to the conclusion that proficient and struggling readers both look at graphics while reading, but possibly for different reasons. Whether and why students look at and use graphics of course depends on the reading situation. Yet in each of these studies, the question of *why* proficient and struggling students might look at graphics, and how their reasons might differ, was not considered.

Besides reporting looks, and time looking, at graphics, there has been little research that compares students' reading processes to reading performance, possibly because many studies use verbal ability as the individual difference and recall (one of the tasks that measures reading comprehension) as the outcome (e.g. Moore, Chan, & Au, 1993; Winn, 1987). These studies are discussed below. However, verbal ability is only one of the many factors that may influence reading ability. Other factors may include fluency and use of cueing systems such as syntactic and semantic features of the text (Moje, 2005). To thoroughly understand if, when, and how students use both prose and adjunct graphics, we should consider the strategies, such as use of cueing systems, and the processes students undergo to comprehend science texts – not just verbal ability.

Spatial and verbal abilities and preferences

Although I do not focus on spatial and verbal abilities in this dissertation, such abilities have been the foci of studies regarding prose and graphics. For example, Moore, Chan and Au (1993) reported that higher verbal ability directly influenced students' recall of details and main ideas from a passage about city growth, and indirectly influenced time spent on the associated tree diagram.

Studies have also shown little correlation of spatial ability with outcome measures such as recall, frequency and time spent looking at the graphic. For example, in the same study by Moore and colleagues (1993), students' spatial ability had no effect on recall. The researchers did not report the influence of spatial ability and time spent on the word or tree summaries, but the presented data suggested no significant correlation between the factors. In addition, Hegarty and colleagues (1991) reported that the frequency with which students made checks with a diagram was similar for *both high and low spatial* ability students as the complexity of the diagram increased. These studies suggest that there is no correlation among students' spatial abilities and their use of graphics when reading scientific texts.

A more recent study also noted that verbal and/or visual *preferences* had no relation to learning outcomes from either visual instruction (involving a combination of tree diagrams and arithmetic) or verbal instruction (involving a combination of text and arithmetic) (Kolloffel, 2012). The authors additionally reported that ironically, one's spatial visualization ability was a major factor in learning via verbal instruction – that is, via "non-spatial representational formats" (p. 704).

Motivation and Interest

How students integrate prose and graphics not only depends on the cognitive strategies used by the learner to solve the respective tasks, but also on the individual's motivational attributes (Schnotz, Bannert, & Seufert, 2002; Schnotz, Picard, & Hron, 1993). Guthrie and Wigfield (1999) expressed how motivation fits into reading texts by stating,

> Constructing meaning during reading is a motivated act. An individual interacting with a text for the purpose of understanding is behaving intentionally. During reading, the individual performs deliberately and purposefully. If the

> person is not aware of the text, not attending to it, not choosing to make meaning from it, or not giving cognitive effort to knowledge construction, little comprehension occurs. (p. 199)

This can pertain to each mode of a text, for a student's motivational attributes may reflect how he or she attends to and comprehends prose, associated graphics, or any other mode of the text.

Interest is an interaction and negotiation between the student (including his or her abilities and identity) and the activity (and the sources of intrinsic motivation associated with the activity) (Brophy, 1999; Cordova & Lepper, 1996; Eccles, et al., 1998; Hidi & Harackiewicz, 2000; Krapp, 2002; Krapp, Hidi, & Renninger, 1992; Pintrich & Schunk, 2002). The person-object duality situates interest into three perspectives:

(1) *Personal interest* involves the student's identity and his or her nature as an individual (i.e. individual characteristics). Personal interest is considered a stable orientation, and it incorporates students' value of, and positive affect toward, expressed ideas in the text (Guthrie & Wigfield, 1999).

(2) *Interestingness* involves the characteristics of the activity (the context) or environment (the situation). The interestingness of a text or context can generate situational interest, "a temporary state that is elicited by specific features of the text" (Schiefele, 1999, p. 258). Specific features of texts that researchers believe can promote situational interest include novelty, surprise, complexity, ambiguity, certain themes, and contextualization (as described later) (Hidi, 2000; Hidi & Harackiewicz, 2000; Pintrich & Schunk, 2002).

(3) *Interest as a psychological state* is the interaction between interestingness and personal interest (Krapp, et al., 1992; Pintrich & Schunk, 2002).

Halkia and Mantzouridis (2005) reported students' interest in science popular press articles that involved graphics. The authors concluded that students might choose to read science articles depending on the graphics in the text. Students did not select science popular press articles that contained diagrams and abstract graphs. Instead, the articles students chose to read included "evocative" pictures. The results of Halkai's and Mantzouridis' study indicate that students' interest in graphics may have some influence on their reading processes. Yet there has been no major effort to identify the interaction of students' interests (in the graphics and the text) with the ways they engage with and use graphics. Through interview questions, I captured students' interest in the text topic before and after reading, as well as students' interest in the graphics in each text after they read the text and analyzed the graphics. My analysis relates each student's interests to the prose and/or graphic (or lack thereof) and to how he or she read and engaged with the constructed expository texts.

Contextualization: Relating Science to Students' Lives to Support Interest, Engagement, and Learning: Contextualization and contextual features have been portrayed in various ways. In science education, *contextualization* is a means of supporting science learning environments by situating the science within a context that relates to students' real-life experiences (Krajcik, Czerniak, & Berger, 2003). In doing so the connection of real-life contexts with the often decontextualized science ideas motivates and guides students' interactions with, and learning of, the science ideas (Rivet & Krajcik, 2008). In a broad sense, contextualized instruction can mean inclusion of any type of context, real-life or fantasy, inside or outside the school setting, which may be meaningful for students.

Though not always called *contextualization*, the notion of providing contexts that connect science with students' lives appears in research and has been incorporated into science and/or math classrooms in many ways. For example, The Cognition and Technology Group at Vanderbilt (CTGV) developed instructional tools (such as the Jasper project) which "anchor" instruction into contexts meaningful to students (1992a; 1992b). Contextual elements also support learning when brought into a science classroom and integrated with the exploration of phenomena (Rivet & Krajcik, 2008). Contextualized instruction is embedded as a primary component of Project-Based Science, and is recognized via four characteristics (Krajcik, et al., 2003; Rivet & Krajcik, 2008). Two of these characteristics relate mostly to using connections to students' lives: (1) to include use of problems and situations that are meaningful to students and provide experiences that will support students' engagement of the science content, and (2) situating the problem by an "anchoring event" (Rivet & Krajcik, 2008). Other instructional approaches that connect to students' lives include providing real-world contexts by studying the local environment (e.g., weather and animal diversity (Lee & Songer, 2003; Parr, Jones, & Songer, 2004)) and utilizing school-community partnerships

(Bouillion & Gomez, 2001). The notion of using contextual features in science class has also been studied in the form of intertextual links – that is, links made by students and/or the teacher between real situations and the chemical ideas surrounding those situations at the microscopic and symbolic levels (Wu, 2003). The use of contexts meaningful to students is also found in motivation literature; Cordova and Lepper (1996) have shown that situating the instructional material in meaningful contexts, whether "real" or fantasy, can support students' intrinsic motivation. Hidi and Harackiewicz have also shown that contextual factors can influence situational interest (Hidi, 2000; Hidi & Harackiewicz, 2000).

Contexts meaningful to students can and have been embedded in texts. For example, as I discuss in the next chapter, the texts in this study followed the IQWST reading materials design principles, one of which is to apply and connect real-world examples (i.e., examples that students most likely have directly or indirectly experienced) to the learning goals. The focus of such inclusion, however, was with respect to prose. Also, Martins (2002) noted that textbook images can serve many functions, one of which is "to establish relationships between the real everyday and the abstract scientific" (p. 76). Martins discussed the contextual nature of images with reference to a report of curriculum development efforts in Brazil in which such images were used as "structural axes" (as cited in Martins, 2002). Martins explained that textbook images were the means by which the recommendation for contextualizing instruction was fulfilled. The examples Martins provided, however, were of images that contained no specific scientific ideas. This dissertation is more extensive because it is of students' engagement with graphics that contain scientific ideas as well as possible meaningful contexts.

DESIGN OF INSTRUCTIONAL MATERIALS REGARDING TEXTS WITH PROSE & GRAPHICS

Schlag and Ploetzner (2011) clearly articulated the ways curriculum design can facilitate learning through use of prose and graphics. They stated,

> There are two main approaches available to facilitate learning with text-picture combinations: either the learning material can be "optimized" through the implementation of various *design principles*, or the learners can be empowered to competently deal with representations through the use of learning strategies. The goal of both approaches is to improve the intake and processing of information. (p. 924)

In this section I briefly summarize research about the two ways to support students' comprehension of texts with prose and graphics: (1) text design and associated design principles and (2) instruction on reading strategies.

Text Design and Design Principles

As Schlag and Ploetzner (2011) also suggest, most research about texts with prose and graphics focus primarily on the improvement of comprehension through design of the texts. Recent discussions about comprehension of graphics and multiple representations have utilized cognitive theories to develop instructional design principles. In fact, Hegarty (2011) reviewed cognitive perspectives with respect to graphic design. Hegarty summarized principles of effective graphics into categories: those related to task specificity, expressiveness of displays, perception of displays, semantics of displays, pragmatics of displays, and usability of displays.

The development of design principles for graphics, or prose and graphics together, tends to incorporate cognitive load theory and the three types of load that can support or hinder working memory: intrinsic, extraneous and germane.[7] The focus in reducing extraneous load has mostly been on developing effective prose and graphics. As Schnotz (2008) mentions, "instructional design should aim to decrease extraneous cognitive load" (p. 20). Indeed, research has determined ways to decrease extraneous load so that readers can better comprehend prose and graphics. For example, Mayer (2001) provided seven principles in designing effective multimedia texts based on his research of student learning through prose and graphics. Some of these, such as the coherence principle and the spatial contiguity principle, can aid in reduction of extraneous processing.

Relationships of cognitive load theory and prior knowledge have also been used to discuss instructional design of representations in science. Cook (2006) discussed the following considerations: multiple representations, dual-mode presentations, split-attention material, narration, redundant material, animation, material with interacting elements, and instructional guidance. With each consideration the author discussed

[7] For recent descriptions of cognitive load theory, the three types of load, and implications and/or considerations with respect to use of multiple representations, see Schnotz and Kurschner (2007); Cook (2006); and Hegarty (2011).

research and sometimes included possible ways to reduce cognitive load. For example, in considering dual-mode presentations and split-attention effect (which may be applicable to this dissertation), Cook first argued that students' learning should be more productive with dual mode presentations (e.g., prose and graphics) than either of those representations alone. He(or she) then used dual mode presentations and dual coding theory to discuss split-attention effect, which can increase extraneous load. Cook detailed possibilities for improving instructional materials design that requires split attention, such as by facilitating students' integration of the different representations (e.g., via color-coding and presenting information proximately in space and/or time).

Also, based on Schnotz and Kurschner's (2007) "reconsideration" of cognitive load by incorporating the zone of proximal development, Schnotz (2009) emphasizes that instructional design should recognize situations in which cognitive load should not be reduced. The authors also suggest that instructional design should focus not on making cognitive processing easier (e.g., by reducing cognitive load) but instead on encouraging cognitive processes that are within the abilities of the students and that support learning. In his 2009 report, Schnotz also recognizes the need for supporting students in knowing about and using strategies as they engage with prose and graphics. Schnotz stated that

> …successful teaching and learning with multimedia is not only a matter of instructional design. It is also a matter of the learner's strategies and his/her own initiative to apply these strategies. A central question is what possibilities exist to make learners more engaged into this kind of processing. (p. 40)

This comment implies the need for students to be competent in their use of multimodal texts, which can be supported by instruction around comprehension strategies.

Design of Instruction around Strategies for Comprehending Prose and Graphics

The aforementioned lack of research on design of instruction around students' use of learning strategies (viz., Schlag & Ploetzner, 2011) is possibly due to the dearth of research on what students already do when reading texts with prose and graphics. (I touched on literature about students' use of reading comprehension strategies in an earlier section of this chapter.) The lack of literature on students' learning strategies with prose and graphics also highlights an imbalance between how we talk about and teach (and how we suggest teachers should teach) reading comprehension strategies for solely prose, and how we talk about and teach (and suggest teachers should teach) strategic use of prose *and* graphics while reading.

In fact, a report by McTigue and Flowers (2011) shows a possible repercussion of this imbalance. To preface their study on students' perceptions of diagrams and skill in interpreting diagrams, McTigue and Flowers described how their instruction to students on reading science texts focused on the structure and technical vocabulary in the prose, "but we rarely spent time teaching about science graphics" (p. 579). They later pointed out that even though more science texts have been introduced in elementary grades, such exposure will not ensure students' use of the graphics in those texts. The authors also referred to other reports showing that teachers rarely explicitly teach students how to use the science graphics in their texts. They stated that "…observations of teacher read-alouds documented that the majority of teachers tend to avoid complex graphics (Smolkin & Donovan, 2004) or simply point to them without offering further instruction" (p. 585). McTigue and Flowers (2011) suggested possible ways to support readers, such as by modeling the interpretation of graphics in a read-aloud task or by having students perform tasks such as creating graphics. However, research on these instructional methods has not been reported.

As mentioned earlier in this chapter, Schlag and Ploetzner (2011) have provided instruction for readers to use what they call a learning strategy (a list of strategies to perform on both prose and graphics) and showed that implementation of such instruction resulted in significant learning gains. However, the learning strategy was developed based on cognitive models of prose-graphic processing (e.g., Mayer, 2001; Schnotz & Bannert, 2003). Development of the learning strategy does not consider what students might already do, nor does it reflect possible interactions between the students' and texts' characteristics.

This dissertation does not focus on instruction. However, better understanding of the ways students engage with the prose and graphics of science texts could possibly generate other suggestions for methods to help readers utilize prose *and* graphics as they access and comprehend texts' science ideas.

SUMMARY OF THEORETICAL FRAMEWORK & RESEARCH REVIEW

Prose and graphics are tools in both communicating and conceptualizing science ideas. Students must be competent in accessing information from both prose and graphics as they read and make sense of science texts.

In this dissertation I use both the interactive models of reading and prose-graphic processing models to guide interpretation of the data. By focusing on students' engagement with prose and graphics in the context of reading scientific texts with certain affordances and limitations, this dissertation can provide information to support a comprehensive theory of multimodal reading comprehension.

Of the collective literature on reading science texts with adjunct graphics, some provide guidelines to answer the research question. These reports are summarized in Table 2.1. I discussed each of these reports in various sections of this chapter. The table includes research that reflects what students *do* with prose and graphics when reading. This table involves readers' cognitive and metacognitive processes in the context of reading texts with prose and graphics. It also includes discussions about why students might use graphics, beliefs about the importance of graphics, and findings about frequency with which students look at graphics. Some research on these topics also incorporated individual characteristics as factors in prose-graphic comprehension and in effectiveness of graphics.

Table 2.1. Summary of Research: What Students Do when Reading Prose & Graphics

Facets of Prose-Graphic Use by Author & Summarized Result(s) and/or Hypotheses

Cognitive Processes in Reading [Science] Texts with Prose & Graphics

Holliday, Brunner, & Donais (1977)

- Students of low and high spatial ability may be processing the graphics differently.

Moore & Scevak (1997)

- Older students demonstrated prose-tree diagram integration strategies; younger students did not.

Cromley, Snyder-Hogan & Luciw-Dubas (2010)

- Students made more verbalizations and use more types of cognitive processes with prose than with graphics.

- Students provided more inferences and more high-level strategies when talking about graphics than with prose (and those with more inferences about graphics had better post-test measures).

Canham & Hegarty (2010)

- Knowledge can affect the way an individual accesses information from complex graphics (based on study of only graphics).

Metacognitive Processes & Awareness of Graphics (and Graphic Use) in [Science] Texts

Craig & Yore (1995; 1996)

- Students are aware of the function of graphics – metagraphical awareness.

Mokhtari & Reichard (2002)

- Using graphics for understanding falls under global reading strategies (pertaining to use before reading).

Why students use graphics

Yore et al. (1998; 1991)

- To help them understand text.

- To clarify, organize, reinforce, enrich, or verify the meanings made.

Hegarty et al. (1991)

- Because of difficulty understanding.

- To check mental representation.

- To reactivate information they internalized earlier.

- To internalize information not yet communicated in prose.

Table 2.1. Cont'd

Facets of Graphical Use
by Author & Summarized Result(s) and/or Hypotheses

Beliefs of Importance & Interest in Articles

Alexander & Kulikowich (1994)

- Novices selected definitions in the form of prose as important, whereas experts preferred equational definitions.

Halkia & Mantzouridis (2005)

- Students may choose to read science articles depending on the graphics in the text; they tend to choose articles with pictures vs. with diagrams and abstract graphs.

Time spent on & frequency of looks to graphics

Rusted & Coltheart (1979)

- Proficient readers spent time on pictures before reading and rarely looked during reading.
- Struggling readers frequently moved back and forth between prose and pictures.

Carney & Levin (2002)

- Increased text difficulty resulted in more frequent looking at adjunct graphics.

Palincsar, Dalton & Magnuson (2005)

- Struggling readers looked more at a graphic than proficient readers.

Moore, Chan and Au (1993)

- Readers with higher verbal ability spent less time (than lower verbal ability readers) looking at graphics.
- No significant correlation existed between spatial ability and time spent looking at graphics.

Hegarty and Justi (1989)

- People who had more domain knowledge about mechanical systems did not need to refer to a picture.
- Those with more domain knowledge spent more time (than those with less prior knowledge) examining a diagram *with shorter text*.

I used these reports as guides throughout the dissertation. For example, I referred to our knowledge of time spent on and frequency of looks at graphics as I analyzed when students looked at, glanced at, or even referred to the graphics. I also utilized reported ideas about *why* students might engage with graphics when reading (such as difficulty in understanding, to reinforce and/or reactivate information, to gain information not yet read, etc.) to support my own analysis of students' engagement with the prose and graphics. Additionally, cognitive studies have led to better understanding of when a graphic is comprehensible and of reported findings about the instructional effectiveness of graphics. I utilized this knowledge as a means to interpret the findings involving the interaction of students' engagement with the specific texts and characteristics of the prose and graphics (i.e., their affordances).

In the next chapter I turn to my methods of data collection. I describe methods of the study, and I show how I applied and incorporated ideas from the literature into the methods.

CHAPTER 3
METHODS & DATA

In this chapter I report how I conducted a descriptive study on the ways a group of sixth grade students engaged with prose and graphics as they read and made sense of two chemistry texts. The research and focal questions guided my determination of data sources, methods of data collection, and methods of data reduction and analyses. Recall the research and focal questions were:

> Research Question: How do students engage with prose and graphics as they read and make sense of science texts?
>
> Focal Question 1: What patterns emerge with respect to sixth graders' overall engagement with prose and graphics while reading and making sense of the texts?
> Focal Question 2: How do characteristics of each reader interact with how he/she engages with prose and graphics when reading and making sense of the texts?
> Focal Question 3: How do characteristics of the texts interact with how readers engage with prose and graphics when reading and making sense of the texts?

I first describe the participants and materials for this study. I then describe the data and sources of data. I then discuss procedures for data collection and analytic methods.

PARTICIPANTS

I recruited 20 sixth grade students to participate in this study. In using 20 participants, my analysis does not assume generalizability among all sixth grade students. Yet in interviewing 20 participants I could provide rich analytic descriptions of how students engage with texts with graphics, and analyze patterns among the readers. Each of the 11 females (55%) and 9 males (45%) participated in one of two science classes taught by one teacher, Ms. Pippy, at a public school located in a small mid-western city. The school tends to serve about 700 students. Student population at this school tends to be about 60% White/non-Hispanic, 15% Asian/Pacific Islander, 12% Black/non-Hispanic, 4% Hispanic, and 1% American Indian.

I selected participants with the same science teacher because I wanted to control for the students' instructional opportunities. Different teachers may bring in their own instructional practices when teaching scientific practices, such as making scientific explanations (McNeill & Krajcik, 2008) or modeling, or other practices such as use of strategies when reading science texts. Therefore the instruction and teacher could play a role in students' use of graphics as they read and make sense of the science texts. Limiting the selected participants to one teacher helps to control this variable, though I was aware that students even in one class could differ in how they processed each instructional environment in which they participated.

I also selected the students based on their performance on a diagnostic reading assessment.[8] I chose participants based on performance on a reading diagnostic because I wanted the cases to represent the range of reading ability among students in a classroom. Based on my theoretical perspective and literature review, students' reading strategies are likely to differ among "struggling" and "proficient" readers. In sampling students with a range of reading abilities, I was able to analyze within and across groups of students based on their reading performances.

MATERIALS – THE TEXTS

The texts I chose for this study are excerpts from the *Smell* unit's reading materials. The students read these texts during my interviews with them. These texts were also the context in which I asked students about their interpretations, interests, and actions toward reading texts with graphics. The texts are shown in Appendix A. Here I provide a general description of the texts in this study. (Chapter 5 provides more detailed descriptions of each text.) I also highlight how and why these texts were developed, and why I chose these specific texts.

[8] I describe how I used the SARA reading diagnostic to select and group the participants in detail in the Data Collection section of this chapter.

General Description of the Texts

Both texts in this study are similar in that they explain real-world phenomena involving the particle nature of matter and the movement of molecules with respect to temperature. The first text, "*Why should I think of molecules when choosing which oven to use to heat my food?*" discusses how microwave ovens work, compared to conventional ovens. The prose in this text first explains how conventional ovens heat the air, which then heats the food in the oven. Then, the prose explains how microwaves are used to heat foods in a microwave oven. Two graphics are included in the text. One graphic depicts information about food being heated by a conventional oven. The second graphic depicts information about how microwave ovens work to heat food. Herein I call this text *Cooking with Ovens*; I call the graphics MW1 and MW2, respectively.

The second text, "*How can molecules make bitter foods taste better?*" discusses chemicals, called bitter blockers, which can reduce the amount of bitterness tasted in foods. The prose in this text first provides examples of bitter foods, and mentions how food companies compensate for the bitterness in their products. Then the prose introduces bitter blockers and explains how bitter blocker molecules "block" the bitter molecules from being detected by the tongue. Three graphics are illustrated in this text. One is a picture of a cup of liquid, which was not a focus on in this study[9]. The first of the two focal graphics is a depiction of a person's tongue, and labeled parts of the tongue. The second illustrates how receptors on a tongue are blocked by connecting with the tasteless bitter blocker molecules, not allowing bitter tasting molecules to be picked up by taste receptors. Herein I call this text the *Bitter Blocker* text; I call the parts of the diagram BB1 and BB2, respectively.

How and Why the Texts were Developed

Student reading materials are constructed scientific expository texts. Integral to the instructional unit, reading materials provide additional opportunities to engage students with each unit's learning goals and in-class investigations. The texts were

[9] I decided to not focus on the picture because I wanted to focus on graphics that pertained to the scientific ideas in the text. The picture matches the prose in that the prose mentions coffee, and the picture looks like a cup of coffee. However, no scientific ideas are communicated in the picture.

developed as materials for the sixth grade chemistry unit that addresses the driving question, *How can I smell something from a distance?* (herein referred as the *Smell* unit) (Merritt, et al., 2006).

The *Smell* unit is one of a series of middle school science units developed by myself and colleagues as participants of the *Investigating and Questioning our World through Science and Technology* (IQWST) project. The design of the IQWST units followed a learning-goals-driven design model (Reiser, Krajcik, Moje, & Marx, 2003), in which each unit was shaped by, and coincided with, key learning goals that were selected from national standards (AAAS, 1993; NRC, 1996). The *Smell* unit incorporates two major learning goals: the particle nature of matter (that all matter is made of particles such as atoms and/or molecules), and kinetic molecular theory (that these particles move, and move differently at different temperatures and in different physical states). As with all IQWST units, *Smell* was specifically developed to provide opportunities for students to explore the learning goals in multiple contexts, and to provide rich science experiences and learning opportunities to all students, whether from urban, suburban, or rural communities (AAAS, 1990; McNeill, et al., 2003; NRC, 1996). In the classroom, students engage in numerous investigations of matter, and develop their conceptions about the particle nature of matter and kinetic-molecular theory.

Development of the texts stemmed from efforts to create reading materials for each IQWST curricular unit under the guidance of the Curriculum Reader Design Principles (Moje, et al., 2004; Moje, Sutherland, Cleveland, & Heitzman, 2005; Sutherland, Hug, Moje, & Krajcik, 2005). Here I describe three of the Design Principles that were particularly pertinent to the texts I chose to use in this study.

The texts are considerate to middle school students (Armbruster & Anderson, 1985). This means that all representations in the text are sensitive to, and appropriate for, students' grade levels, reading levels, and prior ideas. The texts therefore include analogies and examples that engage students, communicate in prose that is concise but not dense with scientific ideas, and show distinctions between everyday use and scientific use of words while at the same time using everyday language to explain scientific ideas.

Both texts in this study were written with the goal of considerateness for middle school students. For example, the Flesch-Kincaid grade level scores for the *Cooking with*

Ovens and *Bitter Blockers* texts, as calculated by Microsoft Word, are 6.4 and 6.2, respectively. Though this score excludes many reading factors that "considerateness" entails, it does take into account the average sentence length and average number of syllables per word. Both texts are also "considerate" by limiting technical language. For example, in the *Cooking with Ovens* text the phrase *regular oven* replaces the phrase *conventional oven*: "Or, you might choose to heat your pizza by using a regular oven (which is also called a *conventional* oven)." *Regular oven* is then used throughout the rest of the text. In this case, students might not know what a conventional oven is, but more students might be able to identify what is meant by a regular oven. An example in the Bitter Blocker text is the use of the word, *saliva:* "When you chew, the saliva in your mouth (your spit) breaks food up…" Although both *saliva* and *spit* are only used once in the text, the inclusion of, "…(your spit)…" provides considerateness towards those students who might not know what *saliva* is, but might recognize *spit* and can then relate it to *saliva*.

The texts help students connect real-world situations and experiences to the learning goals. Reading materials help to bridge the *Smell* unit's learning goals and in-class investigations with real-world experiences and phenomena that students may experience in their middle-school lives. For example, texts in the reading materials may include analogies that middle school students may have experienced. Both texts I use in this study do involve real-world situations and experiences. One involves the use of ovens to heat food, and the other is about tasting bitter foods. These are situations that students most likely have experienced, and whose underlying science explanations match that of the unit's learning goals.

This principle also includes the use of multiple text genres, and texts of various sources. For example, the reading materials may have embedded real-world texts (such as texts from websites and newspaper articles), and/or embedded *adapted* versions of real-world articles. The articles are adapted when they are too long and/or too difficult for students to read. Adapted versions either (a) entail the original text with the only changes being elimination of sentences or paragraphs that were deemed irrelevant to the main idea and/or goal of the text, or (b) entail reconstruction of the text following the guidelines of considerateness. In the latter instances, however, the content and context of the adapted versions are consistent with, and directly match, the content and context of the original text. The prose of each text in this study follows the latter format. The construction of prose for the *Cooking with Ovens* text was adapted, with content added, from a short newspaper article informing readers that microwave ovens are not harmful to people and foods (New York Times News Service, 1985). The prose of the Bitter Blocker text was an embedded adapted version of a newspaper article (Day, 2003), in which the content remained similar to the content in the original article.

The reading materials use additional representations. This includes situational representations (such as analogies and cases) as well as graphics. They are *additional* representations when used in the reading materials but not specifically used in the corresponding lesson. Many times the representations show other ways of thinking about the concepts. Graphics may also be connected to the analogies or cases represented in the prose. All of the representations are provided with the goal of supporting students to transfer the knowledge to new situations, and scaffolding students' navigation among different representations, whether in or out of the science classroom.

The reading materials for the *Smell* unit are full of graphics that range from macro-scale representations (such as pictures), to symbolic and micro and nano-scale representations (such atoms and molecules), to graphics that incorporate both macro-scale and micro-scale representations. Many of the graphics in the reading materials are also closely associated with the unit’s goal of teaching about modeling – a scientific practice commonly used when learning about the nano-world and when explaining phenomenon with the particle nature of matter and the movement of molecules with respect to temperature. The texts chosen for this study are no exception. Both texts include macro- and micro-scale representations.

Choice of Texts for this Study

Of all the passages in the *Smell* unit’s reading materials, I chose to use the *Cooking with Ovens* and *Bitter Blockers* texts for three reasons. The first is that both the *Cooking with Ovens* and *Bitter Blockers* texts support students in learning and applying ideas about the particle nature of matter and movement of molecules with respect to temperature. The texts are less instructive of the specific unit goals *per se*. These texts do not instruct the reader what atoms and molecules are. Nor do they instruct that particles move faster as temperature increases. Instead the texts are *applicative* of the learning goals. The texts instruct the reader about real-world situations in which the particulate nature of matter, and the movement of molecules with respect to temperature, can be applied. For example, *molecule* is in each of the reading passages, but the texts do not inform students of what a molecule is. Instead the texts use *molecule* to explain how bitter blockers and ovens work. Also, in both texts the prose and graphics illustrate both macro scale depictions and representations of molecules, and use these models to explain how ovens and bitter blockers work.

The applicative nature of the texts also relates to the second reason for choosing the *Cooking with Ovens* and *Bitter Blockers* texts. I wanted to use texts that could be read in various situations; in science class, in a magazine, on the Internet, etc. In this way, students could read the texts whether they did or did not have instruction surrounding the content of the text. Also, most real-world texts that entail the particle nature of matter and/or the movement of molecules with respect to temperature use the science ideas to explain a larger-scale phenomenon that might be of interest to the lay reader. The texts I chose are similar to real-world texts in the same manner.

The applicative nature of the texts, and the various contexts with which these texts could be read, also relate to the third reason for choosing the *Cooking with Ovens* and *Bitter Blockers* texts. By using these texts, this study responds to the call by the National Research Council (1996, 2012) and researchers (e.g., Goldman & Bisanz, 2002) for students to be able to, "read media reports of science or technology with a critical manner so as to identify their strengths and weaknesses" (NRC, 2012, p. 73), to be able to, "engage in social conversation," (NRC, 1996, p. 22) about the communicated information, to develop a, "critical stance toward scientific communications" (Goldman & Bisanz, 2002, p. 44), and to be able to make informed choices after reading, comprehending and learning from the texts.

DATA

Due to the nature of the research and focal questions, three sets of data were used: (1) data on students' individual characteristics; (2) data on the science texts used for this study; and (3) data on students' engagement with the texts. Multiple sources were used to collect the various data types. Data sources included the SARA reading diagnostic, unit pretest and student interviews. Table 3.1 summarizes the sources of data by listing the types of data provided, purpose for collection, and group size for each source. Following the table I describe the three sets of data. Methods for the collection and analyses of these data are described in the next section.

Table 3.1. Data Sources

Data Source	Data Type Provided	Purpose	Group Size
SARA Reading Diagnostic (transcripts & audio)	Student Characteristic: Reading Achievement (Pre-Interview & Integrated)	Assess reading achievement; Identify 20 target students at the struggling, intermediate and proficient reading levels; use with comprehension assessments to determine integrated achievement.	Two classes (N=43)
Unit Pretest	Student Characteristic: Prior Knowledge	Assess prior knowledge of the particle nature matter & kinetic molecular theory.	Two classes (N=50)
Student Interviews (transcripts & video)	Student Reading Engagement	Provide opportunities and document student engagement with prose and graphics.	Target Students (N=20)
Pre-Reading Prior Knowledge Items	Student Characteristic: Prior Knowledge	Assess prior knowledge of (a) particle nature of matter & kinetic molecular theory and (b) content of text topic.	
Post-reading Comprehension Items	Student Characteristic: Integrated Reading Achievement	Assess reading achievement that includes SARA diagnostic and comprehension of the texts.	
Pre and Post-reading Interest Items	Student Characteristic: Interest	Determine students' interest in the text (prose and each graphic).	

Data Set 1: Students' Individual Characteristics

Chapter 2 outlines salient characteristics of readers that may interact with the way they use graphics, including reading ability, prior knowledge and interest. I therefore collected data regarding these characteristics so that I may have an enhanced description of the students and better understand the students' engagement with the graphics when reading and making sense of the texts.

Characterizing Reading Achievement (Pre-Interview and Overall): As noted earlier, I wanted the cases in this study to represent a range of reading performances that can occur among students in a classroom. In doing so I could analyze patterns across readers. The SARA reading diagnostic was used to collect information about, and assess, students' *pre-interview* reading achievement. The SARA is a computerized module, made by Educational Testing Services (ETS) in collaboration with Elizabeth Birr Moje and the Textual Tools (TT) and Adolescent Literacy (ALD) projects (Solomon, Van de Kerkhof, & Moje, 2010). With the SARA diagnostic I obtained information on students' pre-interview reading performance and choose 20 students whose reading achievement levels ranged from low (i.e. more struggling) to high (i.e. more proficient). The diagnostic and the processes involved in participating with the diagnostic are described in the Data Collection and Analyses section.

However, what students do when reading a text (with or without graphics) not only depends on their general reading level, but also their ability to read and comprehend the text they are reading. I therefore also determined students *overall* reading achievement by measuring each student's comprehension of the two texts in this study, and integrating the assessments with his/her performance on the SARA reading diagnostic. (I further describe assessment of comprehension and integration processes in the Data Collection and Analyses section.) By applying multiple sources of reading assessments I was also able to more confidently describe a student as "struggling" "intermediate" or "proficient." I then used each student's *integrated reading achievement* as an individual characteristic in answering the research question.

Characterizing Prior Knowledge: Research has shown that prior knowledge is closely related to text comprehension, comprehension of science content, and use of visual aids in learning about the science content (e.g., Fielding & Pearson, 1994; Kozma, 2000; Schnotz, 2002). Any prior knowledge of the science ideas in each text can provide insight regarding students' comprehension and use of graphics while reading the texts.

Anticipating that students will differ in prior knowledge, I obtained information from two sources to help me determine and describe students' knowledge of the particle nature of matter and kinetic molecular theory. The primary source was a set of pre-reading questions as part of the interview. The secondary source was a collection of items from the pretest for the entire *Smell* unit. I also used the pre-reading questions to describe students' knowledge of ovens and microwaves (other science content in the context of the *Cooking with Ovens* text), and of tasting and taste buds (other science content in the context of the Bitter Blocker text).

Characterizing Student Interest: Similar to prior knowledge and verbal and graphical inclination, research has shown that students' interests (or lack thereof) in the text and/or the graphics may interact with how they engage with texts and graphics (though not necessarily texts and graphics together) while reading and after the reading process (Guthrie & Wigfield, 1999; Halkia & Mantzouridis, 2005). Therefore I collected data on students' interest via multiple parts of the interview. As described under the Data Collection and Analyses section, data on students' interest includes a general student-reported assessment of his/her pre-reading interest (e.g., how interested a student was in reading the text before reading), and student reports of their post-reading interest, specifically focusing on their interest of both the texts and of each graphic.

Summary of Data Set 1: Students' Individual Characteristics

In summary, to characterize students' individual characteristics, I drew on pre-interview measures such as the SARA reading diagnostic for reading achievement and the *Smell* unit pretest for prior knowledge. I also drew specific sets of items in the interview, including pre-reading interest and prior knowledge items and post-reading comprehension and interest items (Recall Table 3.1 also summarizes these sources of data on students' individual characteristics).

Data Set 2: Characteristics of the Science Texts

Focal question 3 entails analysis of students' engagement with the texts with respect to characteristics of the texts. What students do, and what they say, when reading texts is also dependent on the features, affordances, and limitations of the prose and graphics. Therefore, in order to provide a coherent and thorough analysis of any student-text interaction, one must first have thorough analysis and understanding of the text itself. Analysis of the texts may also lead to discovery of themes about students' engagement with the texts. Therefore analyses of science texts were included in this study. The perspectives taken for, and types of information drawn from, analysis of the texts is described in the Data Collection and Analyses section.

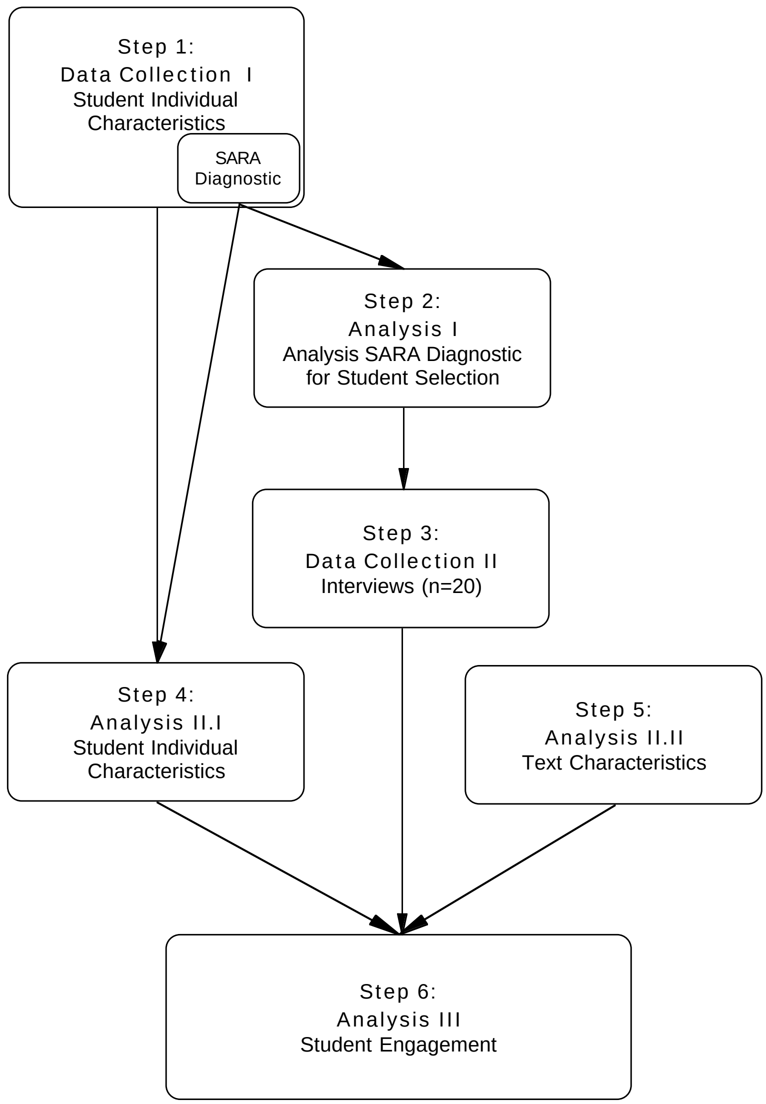
Data Set 3: Student Engagement with Prose and Graphics

Data concerning the ways students engaged with the prose and graphics of each text as they read, made sense of, and talked about the texts were crucial in addressing the research questions. These data were realized through various parts of students' interviews, including a read aloud with think-aloud task, and students' responses to stimulated recall, metacognitive and interest questions. These tasks and the specific information they provided are described in more detail when I describe the interview process in the Data Collection and Analysis section.

PROCEDURES: DATA COLLECTION & ANALYTIC METHODS

The data collection and analysis processes occurred in six steps (Figure 3.1). The first step was Data Collection Part I. In this step, data on students' characteristics were collected with two measures (a pretest and the SARA reading diagnostic). The second step, Analysis Part I, entailed analysis of the SARA reading diagnostic as a measure of students' pre-interview reading achievement, and selection of students based on the SARA analysis results. The third step was Data Collection Part II, which involved interviews with the target students. The fourth and fifth steps involved analyses and occurred in parallel. Step four, Analysis II.I, involved analysis of students' individual characteristics. Step five, Analysis II.II, was analysis of the texts. The sixth and final step, Analysis Part III, involved students' engagement with the texts. My methods of collecting and analyzing the data are described for each step.

***Figure 3.1.* Data Collection and Analyses Processes**



<u>Step 1: Data Collection Part I</u>

The first part of the data collection process consisted of students taking the SARA reading diagnostic and completing measures of prior knowledge via the unit pretest.

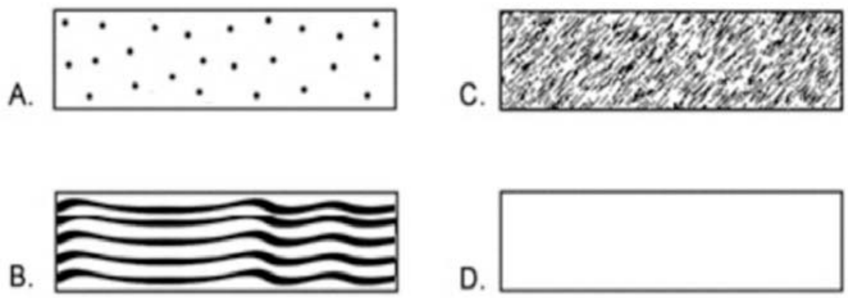
Collection of Students' Pre-Interview Reading Achievement Data via SARA Diagnostic: Students from two science classes took the SARA reading diagnostic, excluding those who were absent and those without permission (43 total). Students took the reading diagnostic before beginning the *Smell* unit. As mentioned, the SARA diagnostic is a computerized module. This module recorded students' voices as they performed the tasks of the reading diagnostic (e.g., as students read texts, talked, responded to questions, etc).

When taking the diagnostic, students performed tasks similar to a qualitative reading inventory (Leslie & Caldwell, 2000). Students first completed a word recognition task. They read words out loud as the words individually appeared then disappeared on the screen. The students then completed a reading task in which students first read silently a passage about a new mechanical bed that has multiple wake-up alarm systems. After reading the passage silently, they were then asked to read the passage again but out loud. After reading, the students answered four questions that asked the student to tell: (1) the main idea of the passage, (2) a possible title of the passage, (3) what the student found interesting about the passage and (4) if there was anything the student found difficult when reading the passage. The student then read two more passages (one about the immune system; the last about a boy who has AIDS and raises public awareness of people who have AIDS). These two passages were also read first silently, then aloud. After reading each passage the student responded to the same four questions stated above. Students' responses to the main idea questions and title questions (for each of the three texts) were transcribed. I used the transcriptions and audio recordings in my analyses.

Collection of Prior Knowledge Data via the Unit Pretest: Students also took the *Smell* unit pretest just before beginning the unit. Excluding those who were absent and those without permission, 50 students completed identical pretest measures. The pretest included 15 multiple-choice and 4 open-ended items. The data I focused on included students' answers only to those items that specifically addressed either the particle nature of matter or movement of particles relative to temperature. This involved a total of 12 questions – 10 of which were multiple choice, and 2 open-ended (Appendix B). Of the 12 questions, 7 addressed the particle nature of matter (5 multiple choice and 1 open ended), and 5 addressed movement of particles relative to temperature (4 multiple choice and 1 open ended). Figure 3.2 shows two of the multiple-choice items. I used responses to these items from the pretest as one measure of students' prior knowledge of the particle nature of matter and kinetic molecular theory.

Figure 3.2. **Example Pre-test Items**

1. **Below are four possible models of a gas.** Which model would a scientist use to explain how water vapor condenses to a liquid?



4. **If you could use a powerful microscope to see the particles in a gas, what would you see between the particles in a gas?**
   A. More particles
   B. Air
   C. Empty space
   D. Liquid

<u>Step 2: Analysis of SARA Reading Diagnostic and Student Placement</u>

I performed the first set of analyses in order to determine each student's initial, pre-interview, reading achievement and to identify 20 students of varied reading achievement to further study via individual interviews. Table 3.2 summarizes the analytic method and description scheme for the SARA diagnostic.

Table 3.2. SARA Reading Diagnostic Analytic Method

Data Source(s)	Analytic Method	Description Scheme
SARA Diagnostic	Content Analysis (Deductive Category Application) - Main idea responses scored via a rubric. Fluency scores based on number of errors. (Fluency scores used to support group placement when needed.)	Categorical: Students grouped according to scores: low; medium-low; medium-high; high.

Measuring Pre-Interview Reading Achievement: Analysis of the SARA reading diagnostic consisted of (a) listening to the recordings of each student's word recognition task to identify errors in reading individual words; (b) listening to the recordings of each student as they read the passages in order to obtain measures of fluency (including errors while reading and words read per minute); and (c) using transcriptions of each student's responses to the main idea questions to obtain a main idea score. Measures of fluency, errors while reading, and main idea measures were assessed for each of the three texts students read.

The main idea responses of each text were scored according to the 2007 SARA rubric developed by members of the ALD and Textual Tools groups (Appendix C). Each response was scored by two independent raters – myself and a fellow graduate student who was also a member of the research group and was involved in the rubric-development process. Both of us simultaneously but independently scored each student's responses.

A Cohen's kappa and percent agreement were calculated for inter-rater reliability. Both methods were used to compensate for limitations of each method.[10] The kappa values and percent agreement for the main idea responses of each text are shown in Table 3.3.

[10] For example, percent agreement may be magnified because it does not take into consideration that a certain amount of agreement could be a result of chance. The Cohen's kappa does take into account agreement by chance (Wood, 2007). However, the kappa does not measure the total agreement of the instrument as a whole. Calculation of both statistics therefore provides the best description of agreement among raters.

Table 3.3. Inter-Rater Reliability Calculations

Passage	Cohen's kappa	Percent agreement
Alarm-clock Bed	.65	77
Immune System	.68	77
Boy with AIDS	.51	67
3 Passages combined	N/A	74

The percent agreement was lower than what is generally accepted, and the Cohen's kappa shows moderate to substantial degrees of agreement. To compensate for these lower inter-rater reliabilities, all discrepant scores were discussed by the raters, rechecked with the rubric and example responses for consistency, and an agreed score was assigned.

I also analyzed fluency by listening to each student as they read each text. As students read each text, I marked instances when students made errors, and counted the errors. I also noted the number of words students read in the first minute of reading aloud for each text, and calculated an average number of words read per minute. This fluency analysis added information about students' reading performance.

Student Selection Based on Analysis of SARA Performances: I first used the results of the SARA diagnostic and information from the teacher to identify and remove students who could not decode words, those who were active in an English for Second Language Learners (ESL) class, and those who required special education. I then determined students' reading performances based on values averaged across the three texts, and individual values of the Immune System text. Table 3.4 shows the 20 students I interviewed, their average main idea scores, average rate of reading, word recognition errors and average errors from reading the SARA passages. Table 3.5 includes students' main idea scores, reading rate and errors reading for the Immune System text. I show data solely on the Immune System text because it is most similar to the texts students read during the interview (i.e., constructed expository science text, written with the goal of considerateness).

Table 3.4. SARA Diagnostic Scores and Values of Target Students

Pre-Interview Reading Group and Students	Word Recognition Errors[a]	Average Score / Value[b]		
		Main Idea	Speed (words/min)	Reading Errors
Low				
Blair	3	1.0	104	22
Fran	10	1.3	86	20
Casey	2	1.3	101	14
Garnet	6	1.7	85	20
Dana	6	1.7	111[c]	14[c]
Medium – Low				
Haiden	5	2.0	76[c]	14[c]
Jessie	4	1.7	103	9
Layne	5	2.3	118	6
Macy	3	1.7	140	4
Kris	1	1.7	148	4
Medium – High				
Patel	3	1.7	152	3
Quinn	2	2.7	149	2
Rene	1	2.0	154	2
Neci	1	2.7	169	9
Sam	0	1.7	194	0
High				
Vaan	3	3.0	146	7
Terri	1	3.0	153	5
Xipil	1	3.0	175	2
Walei	5	3.3	138	5
Zavit	1	4.0	167	2

[a] Number of errors out of 20 total words
[b] Average based on all three SARA passages
[c] Student did not read AIDS passage aloud, so average based on Bed and Immune System passages

Table 3.5. SARA Diagnostic Immune System Text – Scores and Values of Target Students

Pre-Interview Reading Group and Students	Immune System Text Score / Value		
	Main Idea	Speed (words/min)	Reading Errors
Low			
Blair	1	99	15
Fran	1	75	30
Casey	1	90	16
Garnet	2	58	26
Dana	1	101	22
Medium – Low			
Haiden	3	66	17
Jessie	3	96	18
Layne	3	90	9
Macy	2	143	6
Kris	1	135	7
Medium – High			
Patel	3	146	2
Quinn	3	152	3
Rene	2	148	2
Neci	2	161	1
Sam	1	199	1
High			
Vaan	3	128	9
Terri	4	140	5
Xipil	3	162	2
Walei	4	117	7
Zavit	4	152	3

I mainly used students' averaged main idea scores to place students into one of four groups. To support placement I used students' reading fluency, word recognition and errors while reading for the Immune System text as well as averaged values.

Based on the rubric, students who scored an average of 4 or higher had consistently incorporated either a majority of instructionally important details in the passages, or provide complete inferences that include the key relationships among elements, characters, events or phenomena in each text. These students would be considered high readers. However of the 43 students, only 1 consistently scored a 4 in each of the three SARA texts, and no students provided a complete inference or summary (a score of 5). Some students did score a 4 with one of the SARA texts, yet scored lower on the other texts. Due to this outcome of students' performances, I decided to change the criteria for selecting the high reading achievement group. This group instead consisted of students who scored an average of 3 or above. These students must have either scored a 3 on each of the three texts, or scored at least one 4. Note in tables 3.4 and 3.6 that the students placed in the high group made 1 to 5 word recognition errors (a group average of 2 word recognition errors); 2 to 7 reading errors (a group average of 4 reading errors), and read the passages with an average speed of 138 to 175 words per minute (a group average of 156 words per minute).

Table 3.6. SARA Diagnostic Scores (Range and Averaged) per Reading Group

	Pre-Interview Reading Group			
	Low	Medium-Low	Medium-High	High
Word Recognition Errors (of 20)				
Range	2 - 10	1 - 5	0 - 3	1 - 5
Group Average	5	4	1	2
Average Main Idea				
Range	1.0 - 1.7	1.7 - 2.7	1.7 - 2.7	3 - 4
Group Average	1.4	1.9	2.2	3.3
Average Speed (words/min)				
Range	85 - 111	76 - 148	149 - 194	138 - 175
Group Average	99	117	164	156
Average Reading Errors				
Range	14 - 22	4 - 14	0 - 9	2 - 7
Group Average	18	7	3	4

Criteria for the intermediate groups also changed due to students' performances. Originally two intermediate groups would be comprised of students who scored between 2 and 3 (*medium-low)* and between 3 and 4 (*medium-high*). As table 3.6 shows, in both intermediate groups the average main idea scores were as low as 1.7 and as high as 2.7. The placement of the readers into *medium-low* and *medium-high* groups was based mostly by their fluency values.

The values of the *medium-low* readers suggested that the students did have some difficulty with extracting instructional information from the SARA texts, but not as much difficulty as those in the low group (Table 3.6). The values for the *medium-high* group show that the students were similar to the high achievement readers in fluency. Yet their main idea scores suggested these students had some difficulty in reading and making sense of the texts. Note in Tables 3.4 and 3.5 that although some intermediate students were clearly medium-low and others clearly medium-high, there existed some cases in which delineation between the two groups was not as distinct.

Readers were identified as *low achievement* if they scored an average less than 2 for the main idea items of the SARA diagnostic. Based on fluency measures, those in the group made an average of 14 to 22 reading errors (the group average was 18 errors), and read the passages with an average speed of 95 to 111 words per minute (the group average was 99 words per minute) (Table 3.6).

Step 3: Data Collection Part II – Interview

The interviews provided data on students' characteristics as well as students' engagement with prose and graphics. Table 3.7 summarizes the data type collected for each part of the interview.

Table 3.7. Summary of Data Types Collected for Each Portion of Interview

Portion of Interview	Data Type Provided
Pre-Reading Questions	Student Characteristics: - Prior Knowledge - Pre-reading Interest in Text
Read Aloud with Think-aloud Task	Student Engagement with Prose and Graphics
Retell & Comprehension Questions	Student Engagement with Prose and Graphics Student Characteristic: Integrated Reading Achievement
Stimulated Recall, Metacognitive, & Interest Questions	Student Engagement with Prose and Graphics Student Characteristic: Interest in Text and Graphics

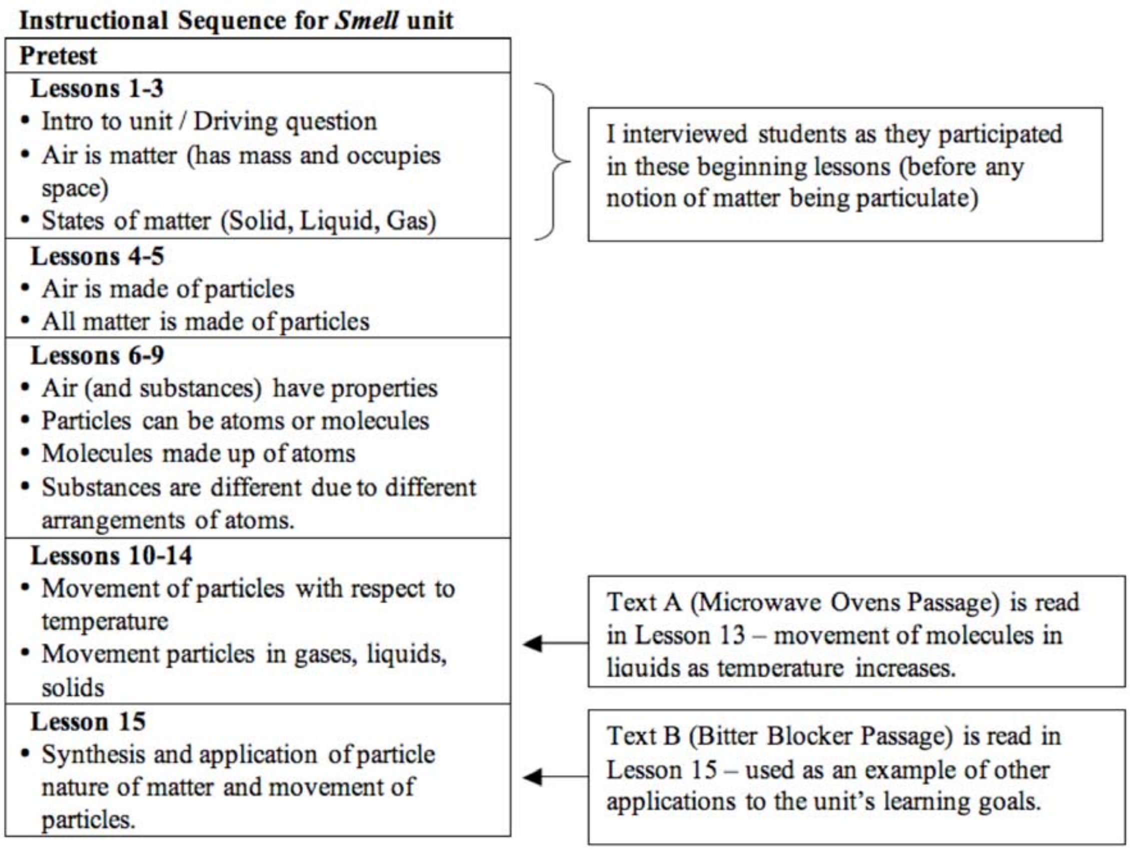
I implemented a within-subject design in which all students read two texts; half of the students read the *Cooking with Ovens* text first and the *Bitter Blockers* text second. The order was switched for the other half of the students. Although within-subject design usually refers to treatment, it is used in this study to allow all 20 students to read both texts, yet in different orders to compensate for possible instances of repetition of tasks, as well as student frustration and cognitive load during the interview.

In using a within-subject design, I structured the interview into two parts. Part 1 consisted of the interview tasks with respect to the *Cooking with Ovens* text. Part 2 involved the interview tasks with respect to the Bitter Blocker text. I was therefore able to set up each interview such that about half the students from each reading group would begin the interview with Part 1, and the other half would begin with Part 2. Appendix D shows each student by initial reading performance level (as assessed by the SARA diagnostic), and with which part they participated first. Because each SARA reading achievement group has an odd number of students, I could not obtain an even order per group. However, the low and medium-low groups together include five students who engaged with the *Cooking with Ovens* text first and five students who engaged with the *Bitter Blockers* text first. The same was true for the 10 high and medium-high readers.

<u>Choice of Timing to Interview Students</u>

Because the texts I chose were part of the *Stuff* unit, I planned to interview the 20 students individually during a specific window of time. I interviewed students after the class finished the IQWST physics unit on light, *Can I believe my eyes?* and as students began to participate in the *Smell* unit. In doing so, I interviewed students before they engaged in lessons with instructional goals of air (and all matter) as particulate. Therefore, what students did or did not do with the prose and graphics while reading the two texts were not influenced by the instruction that coincides with the placement of the texts in the unit. Figure 3.3 shows the instructional sequence, the interview moments, and the lessons with which students would read the texts as part of the curriculum.

Figure 3.3. **Instructional Sequence of Smell Unit and Interview Moments**



I decided to interview students before formal instruction to reduce the variability of prior knowledge. Students may engage with the texts differently because of prior knowledge. The point in which students have had no formal instruction on the chemical concepts would most likely be the point with which students have the least variability.

I also did not want students' learning of the content to conflict or confound their (a) comprehension and (b) use of graphics. Although the graphics in the texts are different from the models students create during the unit, they are not completely different. The forms and functions of representations students use within their models (for example, circles to represent atoms or molecules) are similar to the forms and functions in the graphics. I therefore wanted to reduce the variability of graphical knowledge students may gain by formal instruction. Prior knowledge also entails graphical knowledge – students had not reached the lessons about matter as particulate, nor had they been instructed about modeling the particle nature of matter (for instance, that particles are commonly depicted as circles). Yet even though I could not control for what students already knew before engaging with this unit, pre-test assessment helped me to understand where students were in their prior knowledge.

I also chose to interview students in the beginning of the unit because the design of the reading materials follows the assumption that students have limited prior knowledge. (For example, the materials are written such that a student who missed the class can still read and learn from the texts.) I therefore wanted my interviews to be naturalistic, for I was curious to know what happens when students might read these texts outside of their instructional unit, as students will be exposed to scientific texts outside of the classroom.

I interviewed each of the 20 students individually in a small, open-door room in the back of the science classroom. The entire interview lasted about two 40-minute periods. I scheduled individual meeting days/times based on each student's availability and schedule. When I could, the two parts of the interviews were performed the same day, yet broken by a break. Each part was completed in one sitting. Yet in some cases the two parts of the interviews were performed within a day from each other.

Interview Protocol

Each interview consisted of an introduction, followed by pre-reading questions, reading out loud with a think-aloud process, recall of main ideas in the passage and comprehension questions, and ending with a stimulated recall process in which I asked students interest and metacognitive questions (Appendix E). This protocol was influenced by the Qualitative Reading Inventory (Leslie & Caldwell, 2000), as well as reading comprehension and metacognition studies (Craig & Yore, 1995, 1996; Garner, 1987). An elaborated sequence of the interview follows. Note that after the introduction, the protocol was performed in its entirety for the first text students read, then again in its entirety for the second text.

Introduction to Interview and Think-Aloud Process: At the beginning of the interview I introduced myself and my study. I told each student that the purpose of the study is to observe what students do, and what they think about, when they learn information from reading text. I then talked to each student about the think-aloud process. I modeled this process by solving a Sudoku puzzle. I first began solving the puzzle silently. I emphasized to each student how he/she did not know what I was thinking or doing when I thought silently. I then tried to solve a portion of the puzzle while thinking aloud. I again emphasized the difference, how the student can tell (and sometimes follow along with) what I was thinking and doing when I thought aloud. I also told each student that as he/she reads the text, if I notice points of silence I might ask the student what he/she is doing and thinking. I then followed the sequence below, for each of the two texts students read.

Pre-reading Questions: Before reading each text, I asked each of the 20 students identical questions to influence a purpose in reading, to identify prior knowledge, and to identify interest in the text. The questions for each text are listed as part of the Interview Protocol, in Appendix E.

Three questions (per text) addressed scientific content in the context of the text they were about to read, such as how our sense of taste works (before reading the *Bitter Blockers* text) and what microwaves are and what they do to food (before reading the *Cooking with Ovens* text).

Additionally, I asked two initial questions and their probing questions (per text) regarding students' knowledge of the particle nature of matter and kinetic molecular theory. These two questions provide the primary source of data to assess each student's prior knowledge of the unit learning goals, as mentioned earlier in the Data section. Before reading the first text, students responded to the question, "Tell me about molecules," followed by two probing questions of, "Where are molecules?" and "Give me an example of a molecule." I continued this question before the students read the second text. I did so by informing and reminding each student of his/her original response to the "tell me about molecules" initial and probing questions. I then asked students if there was anything about their first response that they would want to add or change. These questions allowed me to more thoroughly assess students' prior knowledge of the unit's learning goals, as well as identify any changes in students' prior knowledge that may have been influenced by reading the first text.

In the second question set, I asked students how molecules might relate to the topic of the text they were about to read. For example, before reading the *Bitter Blockers* text, I asked, "What might molecules have to do with bitter tasting foods?" Before reading the *Cooking with Ovens* text, I asked students, "What might molecules have to do with heating food?" These questions served two purposes. The first was to provide an assessment of students prior-reading knowledge of the particle nature of matter and kinetic molecular theory. The second purpose was to describe students' prior knowledge of the content in the *context* in which the information applied.

In the last portion of the pre-reading questions, I showed students the text, read the title of the text, and asked students to predict what the text will be about based on main ideas that I asked with the previous questions. I then asked students of their interest and curiosity toward the topic. Students rated their interest on a scale of one-to-five, and each provided a reason for his/her choice and described what they thought might be interesting about the text. This information not only helped me to identify students' interests in the text, but also helped me to identify the extent to which students' interests involved the graphics within the text.

I recognize that asking pre-reading questions supports a purpose for reading, and allows students to participate in reflection skills before reading. However I justify asking prior knowledge questions because all students, whether proficient or struggling, were given the opportunity to use the questions as cues to their reading. It is also a practice of other reading inventories, and allowed me to assess prior knowledge and motivation to read the text.

Read Aloud with Think-aloud: I then asked students to read out loud, and to think-aloud (Ericsson & Simon, 1984; Garner, 1987) while reading. The think-aloud provided a verbal report of students' thought processes, which in turn provided access to students' reasoning and cognitive actions (Winn, 1991). The use of the think-aloud method is also congruent with Gilbert's (2005) identification of the think-aloud process as the "likely" method for studies on solving problems, "that do or might involve visualization" (p. 3). Though this study does not focus on solving problems *per se*, the "problem solving" students did in this study involved making meaning from the prose and graphics, in which imagery and visualization most likely occurred. Also, studies have used the think-aloud method to identify strategies and/or cognitive activities while reading prose versus reading graphics (e.g., Cromley, et al., 2010). However my use of the think-aloud protocol was to focus on reasoning and cognitive actions that occurred due to the interaction of the prose and graphics together.

Some studies that used a think-aloud method when reading provide stop-points in which the student is asked to stop reading and say what they are thinking (Garner, 1988). I also followed this process, in which I strategically placed green cloud icons throughout the texts. I placed the markers after sentences that communicated science information relating to with the Smell Unit's learning goals, as well as other science ideas important to the text.

I asked each student to think-aloud whenever he/she saw the marker, but told the student that he/she could think-aloud at any other instance while reading. I also prompted students to think-aloud when I noticed the student was silent, especially around the placed markers. I prompted students via questions such as "What are you thinking," "What are you doing," and/or "What are you looking at?"

Retelling of Ideas in Text & Comprehension Questions: After students finished reading, I closed the text and asked students to retell what they read (not allowing students to look back at the text). Retelling without look-backs provides an immediate assessment of students' comprehension. What a student recalls is based on his/her comprehension of, and memory of details within, the passage. Students' retell also reflects information in the text that they might deem important (Winograd, 1984). Therefore, students' responses could have included information from the prose and/or graphics, and help me to identify parts of the texts that the students focused.

I then re-opened the passage and asked students to answer five comprehension questions. Students had the option to look-back at the text as they responded to the questions. Comprehension questions with look-backs allow students to continue comprehending the text, without having to rely on memory (and therefore eliminating possible artifacts of cognitive load in reading, comprehending and memorizing the information). Comprehension questions with look-backs also more closely resemble a real-life reading situation in which the prose and graphics are accessible when making meaning, whether inferential and/or explicit, from the text (Holmes, 1987). For each text the comprehension questions consisted of three explicit questions (in which the student could find the information directly in the text) and two implicit questions (in which the student would need to infer based on what they read) that pertained to the main ideas of the text and closely related to the text's structure (see Interview Protocol in Appendix E). I also used think-aloud prompting questions as they looked back at the text and whenever I noticed the students pause and/or looking at a portion of the text.

Stimulated recall: metacognitive and interest questions: In the last part of the interview, I asked students questions about their reading processes (e.g., what they did, what they had trouble with, any questions they had, any easy or boring or interesting sections). I also asked questions specifically geared toward students' use of and thoughts about the accompanying graphics (e.g., if and when they looked at the graphic, if the graphic was helpful, interesting, etc.). Students' responses to these questions provided information such as (but not limited to): reports of when and why they looked at each graphic; non-prompted references to each graphic when discussing the texts; interpretations of the graphics and their relationship with the prose; difficulties they may have encountered while reading the text; their overall interest in the prose, diagram and text; and ideas how one might change the graphics to support understanding and interest. This information helped me in answering the research and focal questions.

Step 4: Analysis of Students' Characteristics

Analyses of students' characteristics involved content analysis. In some cases the analyses involved inductive category development, whereas in other cases it involved deductive category application. I also transformed students' characteristics into categorical data and used simple quantitative analyses, primarily t-tests and crosstabs with Fischer's exact test, to identify significance of trends among groups of students. Below I describe specific methods used to obtain descriptions of each individual characteristic for each student and characteristics averaged among groups of students (Tables 3.8-3.10). In the next chapter, as I present the reduced data on students' characteristics, I describe criteria and decisions made in categorizing students based on the description scheme for each characteristic.

Integrated Reading Achievement: Characterization of students' integrated reading achievement was based on two assessments. I took into account each student's (1) SARA reading diagnostic performance (described in Steps 1 and 2), and (2) their comprehension of the *Bitter Blockers* and *Cooking with Ovens* texts. In this way I identified proficient, intermediate and struggling students through a process of triangulation. Table 3.8 summarizes the analytic method for students' integrated reading achievement.

Table 3.8. Integrated Reading Achievement Analytic Method

Data Source(s)	Analytic Method	Description Scheme
Interview	Content Analysis – Deductive Category Application:	Integration of measures and reduction into three groups: Proficient, Intermediate, and Struggling readers
Comprehension Questions	Rubric	
Retell Task	Propositional map; guideline questions	
SARA Diagnostic	Analysis described in Step 2	

Responses to the Comprehension Questions and the Retell task comprised the data used to assess students' comprehension of each text. I scored responses to the comprehension questions based on a rubric (Appendix F). Each comprehension question was scored by two independent raters – myself and a colleague. We together reviewed the rubric, and for each question we scored 5 students' responses with discussion and consensus. We then scored 5 students' responses to each question independently, discussed in depth our decisions and came upon a consensus score for each response. We then simultaneously but independently scored responses of the other 10 students. The percent agreement was calculated for inter-rater reliability. Inter-rater reliability was 78% for and 80% for the *Cooking with Ovens* and Bitter Blocker texts, respectively. After independent rating, all discrepant scores were discussed by the raters, rechecked with the rubric and example responses for consistency, and the final score determined.

I also analyzed students' retell to gain more understanding of whether the student had or had not comprehended the text. Students' retell was used to highlight information with which the student might have had difficulties. In analyzing the retell task I used a system similar to Grambrell and Jawitz (1993), and also followed retell analysis procedures from the Qualitative Reading Inventory III (Leslie & Caldwell, 2000). I first separated content of each text into individual propositions, and mapped the propositions to the comprehension questions. The *Cooking with Ovens* text involved 46 total propositions that readers could possibly retell, 21 of which mapped to the comprehension questions. The *Bitter Blockers* text involved 40 total propositions, 17 of which mapped to the comprehension questions. I then matched propositions from students' retell responses to the propositional text content. For each student, and each text, I calculated the percentage of all possible recalled items, and the percentage of all possible recalled items that mapped directly to the comprehension questions.

I evaluated the retellings by the percentages and by asking guideline questions. One focal guideline question was if the retold information supported the comprehension questions. I also used the following guideline questions in my evaluation of the retellings (Leslie & Caldwell, 2000, p. 72):

1. "Did the retelling contain appropriate summary/gist statements or main idea statements?"
2. "Did the retelling support the summary/gist statements or main idea statements with any details?"
3. "Was the retelling generally specific? Did it contain vague and general statements?"
4. "Was the retelling generally accurate?"

Students' comprehension of each text was first determined based on their scores from the comprehension questions. Each student was assessed at one of three levels for each text. These levels were (a) comprehension at a higher level (for scores of 80% and above), (b) comprehension at a medial level (for scores greater than 50% and less than 80%) and (c) little to no comprehension (if scores were less than 50%).

Use of students' retell was most important when a student's comprehension score was exactly 50%. This situation occurred four times for both the *Cooking with Ovens* and the *Bitter Blockers* texts. I used the percentages of retold ideas, evaluated if the retold ideas supported the comprehension questions, and evaluated the retold ideas with respect to the other guideline questions, to assess the students as comprehending (to boost them above the 50% mark), or not comprehending (place them below the 50% mark).

As mentioned, I used both the SARA diagnostic and students' comprehension of the texts to place students into one of three Integrated Reading Achievement groups:

proficient, intermediate and struggling. In Chapter 4 I further describe the criteria used, and decisions made, to place the students.

Prior Knowledge: The basis for my assessment of students' prior knowledge via pre-reading questions follows that students' knowledge may not be entirely cohesive; that people have "knowledge-in-pieces," loosely connected ideas about the world that can be used to generate explanations in particular situations and in response to particular questions or cues (diSessa, 1993). However it is also the cohesiveness and the organized set of ideas into well-connected schemas that separate a novice from expert learner (Pelligrino, Chudowsky, & Glaser, 2001).

The participants in this study were in the process of learning many scientific ideas from their science classes. I therefore analyzed data on students' prior knowledge via two assessments – the unit pretest and pre-reading interview questions for each text. With these two assessments I determined students' prior knowledge of the particle nature of matter. Also with the pre-reading interview questions I assessed students' prior knowledge of the texts' topics: ovens and microwaves, and tasting and taste buds.

Table 3.9. Prior Knowledge Analytic Method

Data Source(s)	Analytic Method	Description Scheme
Interview – Pre-Reading Questions	Content Analysis – Deductive Category Application	Students categorized as high, average and low prior knowledge overall and by content.
Unit Pretest	Rubric: Multiple-choice items scored right/wrong; open ended via content analysis.	

<u>Pre-Reading Prior Knowledge Data:</u> Prior knowledge was assessed by evaluating the level of each idea students provided as well as the relationship of the ideas together, and counting the ideas in each level. I first compiled students' responses to the prior knowledge questions and grouped the responses with respect to the general science ideas students expressed. Each student's responses to the prior knowledge questions were coded to identify all ideas expressed. This was performed by two independent raters – myself and a colleague. We together reviewed the codes for each type of idea students' provided. We then independently coded all 20 sets of responses to each question. The inter-rater reliability was 90% as averaged across all pre-reading prior knowledge

questions and all students. (The lowest inter-rater reliability by student was 82%; the highest, 94%.) After independent coding, discrepant scores were discussed by the raters, rechecked with the coding scheme and example responses for consistency, and the final coding determined.

I then used the *Benchmarks for Science Literacy* and the *Atlas of Science Literacy* (American Association for the Advancement of Science (AAAS), 1993, 2001) to identify levels for each type of idea.[11] Appendix G shows exemplar ideas students provided and each idea's designated levels. I considered the ideas that encompassed the K-5 grades as *at level*. These statements, such as, "taste buds are on the tongue," and, "regular ovens get hot" related to ideas that students should know by the time they reach the sixth grade. Note that no ideas about molecules were *at level*.

The ideas that encompassed the grades 6-8, yet are found in the lower to middle sections of the Atlas were at the *above but in process* level. By *in process* I mean that students were in the process of learning about the ideas. The students may have had already learned a little bit about the ideas, but may not have had comprehensive instruction about them. An example includes the notion of molecules being very small and that one cannot see molecules.

The ideas presented in the upper-most part of the grades 6-8 level, and those at the grades 9-12 level, I considered as *above level* ideas. This level included ideas such as molecules absorb light, and that taste buds detect molecules.

In answering the prior knowledge questions students also made statements that were not correct. I considered these statements misconceptions. The misconceptions indicated the types of inconsistencies students had that could inhibit the cohesiveness of their knowledge.

I categorized students' overall prior knowledge level as low, average or high, depending on the number and quality of articulated ideas. The levels were made with respect to natural deviations among the values and average and standard deviations. I

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[11] Note that the kind of prior knowledge I assessed dealt with molecules (the particulate nature of matter and kinetic molecular theory); microwaves and ovens, and tasting and taste buds. The Atlas and the Benchmarks proved to be the primary resource for discerning levels on ideas about molecules and about microwaves. However the sources supplied little information on ideas about tasting and taste buds. I therefore used the general benchmarks that encompass the ideas of tasting and taste buds (eg. human senses) to ascertain the levels.

understand that this method provides levels that are relative to the set of 20 students. Yet I make the levels and characterize students as members of each level as a way to distinguish students who have higher and lower prior knowledge. In Chapter 4 I further describe the criteria used and decisions made to categorize students levels of prior knowledge.

Unit Pretest Data: The unit pretest data was used with the pre-reading prior knowledge items that dealt with the particulate nature of matter to determine students' understandings of atoms, molecules and molecular motion. Multiple-choice items were scored right or wrong. The open-ended responses were scored according to the Smell test rubric developed by members of the IQWST group. Each response was scored by two of three independent raters, including a fellow graduate student, an associate researcher and myself. All members of the research group were and involved in the rubric development process. After three iterations of trials to support clarity and equivalence of scoring, two of the three raters simultaneously but independently scored each response. A 90% agreement was calculated for inter-rater reliability. Responses with discrepant scores were rechecked by the rubric and example responses for consistency, and a final score was determined. For each student, scores of the specific items were accumulated and calculated into two scores – one on the particle nature of matter and the other on kinetic molecular theory. Scores of the 50 students were then used to calculate averages and quartile ranges. These ranges provided the boundaries to determine the 20 target students' prior knowledge as *low, average,* or *high.*

Student Interest: To characterize students' interest in the text and graphics I focused on the interest questions in the interview. Table 3.10 summarizes the analytic method for characterizing students' interest.

Table 3.10. Interest Analytic Method

Data Sources	Analytic Method	Description Scheme
Interview – Interest Questions		
Pre-Reading	Students rated scale 1-5	Three levels of interest: indifferent; interested; very interested
Post-Reading	Content Analysis	

I asked students about their possible interest in each text during the pre-reading questions. The pre-reading question asked students to rate their possible interest in each text, using a scale of one to five, one being the least interested and five being the most interested. Two follow up questions were asked: a) why they chose the score and b) what they think might be interesting about each text.

I also asked students about their interest of each text and of their interest in each graphic *after* students read the text. These questions (and probing questions) were:

- How interested were you when reading this passage?
  - What made it (interesting/not interesting/rating 1-5)

- Can you show me a part that made it interesting/not interesting?
  - Why did you (not)like this part?
  - Are there other sections you liked?

- How interested were you in looking at the diagram?
  - What parts of the diagram did you like? Why?

Responses to these post-reading interest questions involved students describing their interest with phrases such as, “I was a little interested…”. Some students also provided a number based on the scale of one to five in their post-reading interest responses. However other students only used phrases to describe their interest level. Also, when possible, I used students’ comments in other parts of the interview to provide information on each student’s (dis)interests.

In the next chapter I discuss students’ general interest in a text and/or graphic by three modes: indifferent (e.g., “not really interested”), interested (e.g., “sort of” or “a little interested”) and very interested (e.g., “I was really interested…”).

Step 5: Analysis of the Texts

I analyzed the prose by content and semiotic methods (Table 3.11). To analyze each graphic individually, and each graphic in relation to the prose, I used a semiotic analysis of graphics, as modeled by works of Kress and Van Leeuwen (2006) and Lemke (1998). Both Lemke (1998) and Kress and Van Leeuwen (2006) provide a semiotic analysis of graphics that parallel Michael Halliday’s theoretical notion of “metafunction.”

The system of analysis is based on the idea that the “visual” (i.e. graphical representation) is a semiotic mode, like speech and writing, which must operate among many representational and communicational conditions. Therefore three metafunctions that apply to speech and writing also apply to visual mode. These three metafunctions are *ideational, interpersonal* and *textual*. The ideational metafunction focuses on the signs and symbols of the graphic and what those signs and symbols represent. The interpersonal metafunction takes into account the interaction between the producer and reader of the graphic. And the third metafunction, the textual, takes into account all the elements of the graphic, as well as the interactions between the prose and graphics. These metafunctions are also respectively considered as *presentational* or *thematic*, *orientational* and *organizational* (Lemke, 1998).

Table 3.11. Texts Analytic Method

Representation in Texts	Analytic Method	Description Scheme
Prose	Semiotic and content analyses	4 perspectives: visual; structural; instructional; interestingness
Graphics	Semiotic analysis via metafunctions	

<u>*Approach to Analyzing the Texts*</u>

I analyzed the texts from four perspectives. First was a visual perspective, focusing simply on the layout of each text. I did this because, with print-based texts, both the prose and graphics are visual representations. As described by Lemke (1998),

> The medium of printed scientific texts is first of all a visual one. Even the linguistic meanings are presented through the visual semiotics of orthography and typography, including all matters of page layout as well as choices of font style and typeface sizes, the use of headings and footers, etc. (p. 95)

Therefore the way the parts of prose and graphics are visualized help us understand the ways students use and make meaning from the text as a whole.

The other three perspectives were based upon Schellings and Van Hout-Wolter’s (1995) report of approaches to identifying the main ideas of a text. They consisted of a “linguistic approach”, which assumes the text structure determines the main ideas in the text; a “cognitive-psychological approach”, which focuses on readers’ goals, interests and prior knowledge to determine the main idea; and an "educational" approach, which considers the instructional and curricular objectives in determining the main idea. I used adapted versions of these approaches as a way to organize the analyses. I therefore focused analyses of the prose and graphics by their structure (i.e., an adapted linguistic approach), interestingness (i.e., an adapted cognitive-psychological approach), and instructional content (i.e., an adapted educational approach). In organizing the analysis by these perspectives I could identify prominent ideas within the prose and graphics with which students may engage. The next section further describes how I analyzed the texts by each perspective.

Visual: The visual perspective involves the layout of each text. This includes how the prose is situated; where headers are located; and where the graphics were placed. The visual also identifies apparent monochrome and/or colored aspects of the entire text.

Structure of Prose and Graphics: Analysis of the structure of the prose focuses on verbal patterns used in expository texts (e.g., Meyer & Freedle, 1984; Vacca & Vacca, 1993). I also represent the structure of the prose by a flowchart as another means of showing how features of the prose shape the structure of the entire text (Goldman & Bisanz, 2002).

Most information I gathered about the structure of the graphics was based on analysis of the graphics' ideational metafunction.   This includes the signs and symbols of each graphic and what those signs and symbols represent. "Any semiotic mode has to be able to represent aspects of the world as it is experienced by humans. In other words, it has to be able to represent objects and their relations in a world outside the representational system." (Kress & Van Leeuwen, 2006, p. 42). The ideational metafunction of graphics incorporates two patterns of representation, narrative and conceptual. Narrative representations depict momentary relations, whereas conceptual representations portray permanent relations among the participants in a graphic. A graphic's signs and symbols may pertain to one pattern, or to both simultaneously.

Each pattern is further delineated into various "processes". These "processes" are classifications of the ways the signs and symbols in the graphic represent and provide a narrative or conceptual pattern. For example, vectors are a type of process because they are commonly used to represent a narrative pattern. Vectors are one of many indications that a graphic has a narrative structure. “In abstract images such as diagrams, the narrative processes are realized by abstract graphic elements – for instance, lines with an explicit indicator of directionality, usually an arrowhead.” (p. 59) Circumstances are another set of elements that support a narrative structure. Circumstances are secondary signs and symbols that, if left out, would not affect the major information that the narrative pattern tells. Lack of circumstances would, however, result in loss of information. An example of a process within conceptual patterns includes any representations that show classification and analytical features. For example, tree-diagrams are classificational processes, and representations that show parts of a whole are analytical processes. These processes indicate conceptual narratives.

For this analysis I determined the features of each graphic that made it fall into the narrative or conceptual category, as well as those features that were described as corresponding processes incorporated within each pattern. I then used the information from this analysis to describe the graphics’ structure.

In describing the structure of each graphic I also used information from analysis of the graphic’s textual metafunction. Recall that the textual metafunction takes into account all the elements of the graphic, as well as the interactions between the prose and graphics: “Any semiotic mode has to have the capacity to form *texts*, complexes of signs which cohere both internally with each other and externally with the context in and for which they were produced.” (Kress & Van Leeuwen, 2006, pg. 43). Through this metafunction the graphics are described by the layout of its elements, as well as the saliency and connections among elements. Kress and Van Leeuwen also identify how individuals in the western culture commonly interpret information based on the layout. For example, if the layout of elements in the graphic is positioned with a left-and-right pattern, then the left parts are considered “given” (i.e., information the reader is already assumed to know). The right side would be considered “new;” key information, and the “message” of what is to be learned in a text. If the layout of the elements in a graphic is positioned with a top and bottom pattern, the top is considered “ideal,” (idealized or generalized information) whereas the bottom is considered “real” (presenting more specific information, the details). To describe the structure of the graphics I also analyzed the layout, saliency and connections among the elements of each graphic.

Interestingness of Prose and Graphics: Interest is an interaction and negotiation between the student (his/her abilities and identity) and the environment (the activity and the sources of intrinsic motivation associated with the activity) (Brophy, 1999; Cordova & Lepper, 1996; Eccles, et al., 1998; Hidi & Harackiewicz, 2000; Krapp, 2002; Pintrich & Schunk, 2002). "Interestingness," as used by Krapp and colleagues, involves the characteristics of the context or environment (Krapp, 2002; Krapp, et al., 1992). In this case, "interestingness" involves the texts the students read. As the second perspective, "interestingness" encompasses potential interest within the text. I identified the elements of each text that were potentially interesting to students. I used theories and definitions of interest as tools in analyzing aspects of interest from the prose and graphics. In doing so I used the theories and definitions explained in Chapter 2 to identify phrases and images that might be interesting to a sixth grade reader.

For example, Pintrich and Schunk (2002) applied research on interest to the classroom by suggesting ways teachers can foster intrinsic, situational and personal interest. I used some of the suggestions as guidelines to identify interesting components of the texts. These guidelines were:

1. "*Create surprise and disequilibrium in the classroom.* Creating surprise by presenting material that goes against expectations or prior knowledge can create some cognitive disequilibrium on the part of students." (Pintrich & Schunk, 2002, p. 298) Students may become more engaged in order to figure out why the disparities occur as a result of the disequilibrium. Curiosity, a source of intrinsic motivation, may also be instigated by information or phenomenon that is surprising or inconsistent with a student's prior knowledge (Lepper & Hodell, 1989; Pintrich & Schunk, 2002). I therefore identified facets of the texts in which there may be a likelihood of surprise, or idea different from what the student may know.

2. "*Use variety and novelty*." (p. 298) This included variety and novelty of the tasks students do in a classroom, as well as introduction of novel and varied contexts, content and ideas.

3. "*Model…enthusiasm and interest for the content.*" (p. 298) In doing so, one is communicating to the students that the content is interesting. This communication can

come about by features of the text that show enthusiasm (e.g., an exclamation point). However, towards what the enthusiasm is directed must be interpreted by the reader.

4. *Contextualize the material to be learned*. Although Pintrich & Schunk did not directly make this suggestion, the authors recognized Cordova and Lepper's (1996) findings that situating the instructional material in meaningful contexts can support students' intrinsic motivation. Contextual factors can also influence situational interest (Hidi, 2000; Hidi & Harackiewicz, 2000). As described in Chapter 2, contextualization and contextual features have been portrayed in various ways. Some educators have defined a contextual *task* as having characteristics that the students had or will directly experience through daily life. Others maintain that there are many forms of contextualization (such as fantasy innovations), and that contextualization is a means to situate abstract knowledge into a task, problem or a phenomenon so that the student may engage with the abstract knowledge. I use all these descriptions of contextualization to highlight facets of the texts that may be interesting to students.

I also described potentially interesting elements of the graphics by analyzing the graphics' interpersonal (i.e. orientational) metafunction. The interpersonal metafunction takes into account the interaction between the producer and reader of the graphic, "Any semiotic mode has to be able to project the relations between the producer of a (complex) sign, and the receiver/reproducer of that sign. That is, any mode has to be able to represent a particular social relation between the producer, the viewer and the object represented." (Kress & Van Leeuwen, 2006, p. 42). The kinds of relationships between the viewer and the representation include contact (for example, whether something is looking at the reader), size and social distance, subjective and objective attitudes, and action (points of view; the way the image is presented and involvement of the reader to the entities in the image). All of these relationships can influence whether a graphic is deemed interesting by its reader.

The analysis of a graphic's interpersonal metafunction also takes into consideration "markers" for discerning a graphic's abstractness and/or realness. These markers include color (saturation, differentiation and modulation), background setting, representation, depth, illumination and brightness. The degree to which a representation provides each of these markers determines the degree to which the representation is more or less “real” versus “abstract.” The extent to which a graphic is “real” or “abstract” again may interact with the readers’ interest and interaction of that graphic.

Instructional Content of Prose and Graphics: For the instructional approach of the prose, I provide a simple examination of the scientific content that the prose communicates. In doing so, I looked for themes and identified propositional clusters that were consistent in the prose and/or that match the learning goals of the unit.

In describing the types of instructional content communicated by the graphics, I utilized a similar method as I do with the prose. I consider the graphic as a whole, and the instructional components that are represented in the graphic.

Relationships of the Prose and Graphics: For each text I also analyzed the relationships among the prose and associated graphics. Graphics can provide redundant, complementary, and/or new information (Hegarty, et al., 1991; Lemke, 1998). Graphics can also function as tools to complete, compare, contrast, detail, or elaborate upon the associated prose (Goldman & Bisanz, 2002). I compared the structural, interestingness and instructional content of the prose and graphics by tabulating the information from each approach. In the tables I identified the information as incompatible (e.g., missing, new/additional, and inconsistent/contrasting information) or complimentary (e.g., elaborated and similar/redundant information).

Summary of Analyzing the Texts

As discussed, I implemented four approaches toward the analysis of each text in this study. These approaches were: visual; structural; interestingness and instructional. I also compared the prose and graphics in each text, identifying relationships between the representations. The analyses involved semiotic and content analysis. Table 3.12 is a summary showing the foci and/or tools I used to analyze and describe the texts. This included metafunctional analyses that informed the description of the graphics with respect to the graphics’ structural, interestingness and instructional components. The next step involved analysis of students’ engagement with the texts, which incorporated information from both this step (analysis of the texts) and the previous step on students’ characteristics.

Table 3.12. Foci and Tools in Analyzing Each Representation via the Four Approaches

Approach	Foci and Tools	
	Prose	Graphics
Visual	layout, headings, etc.	layout, headings, etc.
Structure	patterns by paragraph	ideational metafunction
Interestingness	guidelines to support interest	interpersonal/orientational metafunction
Instructional	propositional clusters and themes	components as represented visually

Step 6: Analyses of Student Engagement with Prose and Graphics

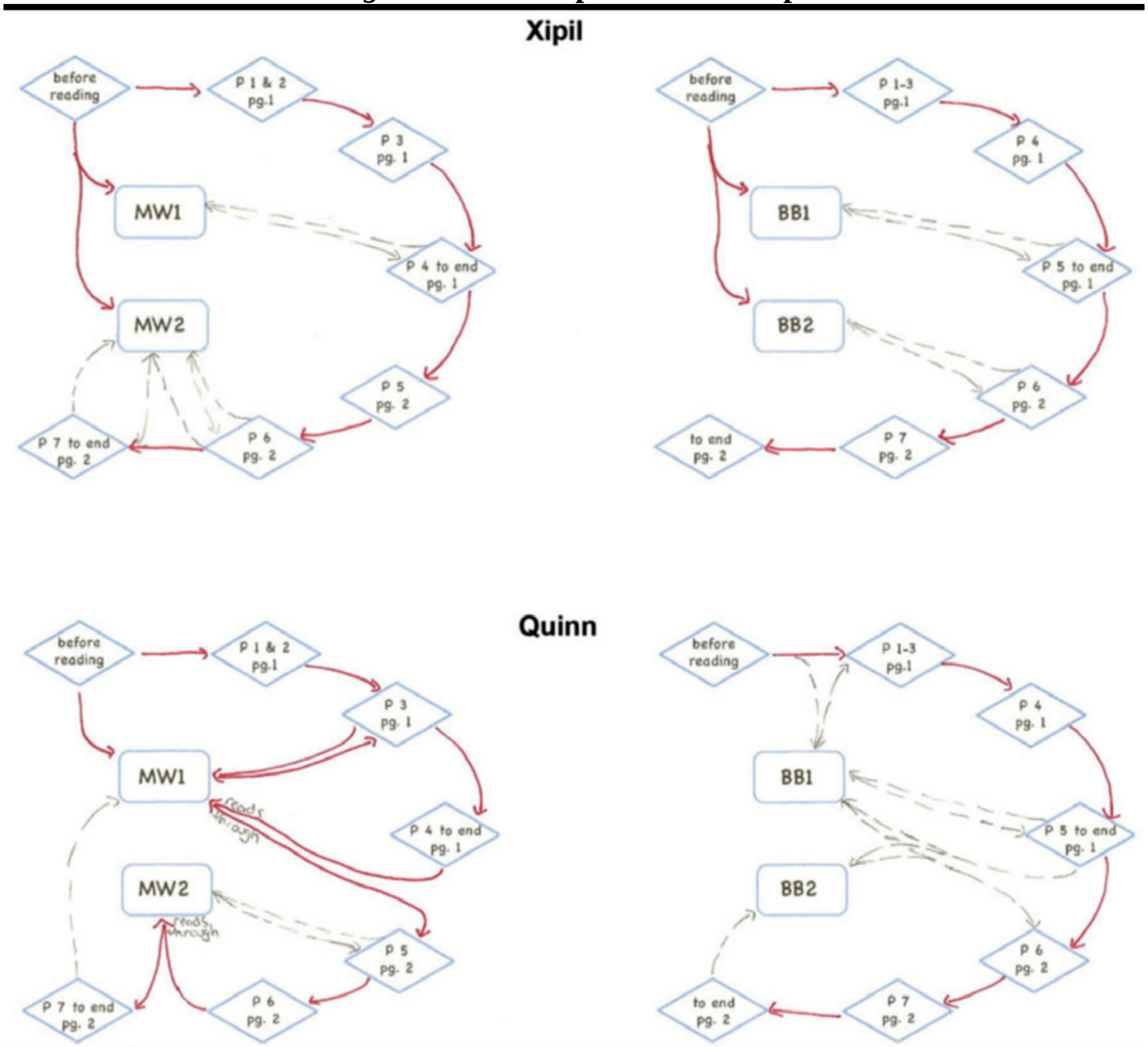
To answer the research questions I focused analyses toward (a) moments students engaged with both the prose *and* graphics while reading, and (b) the interview in its entirety, and themes about students' prose-graphic engagement as represented throughout. Within each focus I used content analyses, constant comparative method and grounded theory to discern patterns, to highlight unique situations, and identify possible mechanisms regarding students' engagement with prose and graphics. I also identified patterns and unique situations by integrating results of the analyses on students' characteristics, textual characteristics and analyses of students' engagement.

Moments Students Engaged with Graphics While Reading

I documented and analyzed moments students engaged with graphics while reading. This entailed students' attention to the graphics. Documentation of each student's attention involved (a) when the student read captions or talked about a graphic; (b) when the student's comments included a feature of the graphic that was not included in the prose; and (c) when a student said he/she looked at a graphic (while thinking aloud and/or responding to stimulated recall questions).

I translated the data into two modes, and used both modes to compare and contrast across texts and student characteristics. The first mode was the frequency of attention. Each student's average frequency of attention per text helped me to specify the extent that students used the graphics. The second mode involved construction of "maps" illustrating the collective instances that each student had indicated attention to each graphic for each text. Figure 3.4 shows an example of two students' collective instances of using graphics as they read the texts. All students' maps are included in Appendix H.

Figure 3.4. **Example Student Maps**



Each student's maps show his/her collective instances of attention to the graphics. The instances each student indicated attention to each graphic was generalized to the paragraphs – before, after, or within a paragraph. Each instance is represented by one of two arrow types. The lighter dashed arrows represent students' self-reports of when they looked at graphic. The darker solid arrows represent students' attention to the graphics based on their think-aloud comments and responses to pre-reading and think-aloud prompting questions. The darker solid arrows also represent agreement between the two sources.

While documenting students' reports of when they looked at graphics, I also documented students' responses regarding why they looked at the graphics. I did this for two reasons. First, based on the interview protocol, my questions to students involved asking when *and* why they looked at a graphic (i.e. the questions were asked conjointly). Second, recognizing that a student's attention may be because of various reasons (including for instructionally and/or personally strategic reasons), I wanted to document and analyze what motivated students' reported looks. The reasons reflect students' own thinking about the strategic ways *they* used the graphic. I could then incorporate students' reasons why they looked at graphics into the descriptions about their prose-graphic engagement.

In this study I also attempted to provide rich analytical descriptions of students' prose-graphic engagement. To obtain descriptions I analyzed across texts and students the instances that students indicated attention to the graphics. I also analyzed specific instances of students' engagement. Table 3.13 lists the methods for each focal analysis.

Table 3.13. Foci and Analytic Methods for Instances of Prose-Graphic Engagement While Reading

Foci of Analyses	Analytic Methods
Descriptions Across Texts & Students	
Frequency Attention	Descriptives; T-tests; Crosstabs & Fisher's Exact
Patterns of Consistency	Visual Comparisons; Percentage Comparison
Reasons Why Looked at Graphics	Constant Comparison; Content Analysis
Descriptions at Instances	
Popular – Characteristics for Popularity	Content Analysis
Instructionally Complementary Instances	
Frequency Attention Across Students at Instances	Descriptives; T-tests; Crosstabs & Fisher's Exact
Mechanisms of Engagement	Constant Comparison Grounded Theory

Analyses to Describe Attention Across Texts and Students: I used students' frequencies of attention to explore engagement among the prose and graphics compared with respect to the students' reading achievement and prior knowledge, as well as by graphic. I did so with simple descriptive analyses, t-tests and crosstabs with Fisher's exact statistical calculations. I used these analyses as a background to the general description of students' prose-graphic engagement.

I also used the frequencies and maps to investigate patterns of consistency in students' attention to graphics when reading any text. If students used the graphics strategically then it is possible that consistency in their reading processes may exist across students and/or across texts. Patterns of consistency could then be identified as ways students used the graphics when reading and making sense of the science texts. Consistency was explored by comparing the collective instances of attention for each text. Students were considered consistent across texts if the percentage of similar instances exceeded the percentage of dissimilar instances.

I then explored students' reasons why they looked at graphics. I labeled and grouped similar responses to form codes that represented students' reasons why they looked at a graphic. Some examples of these codes included (but were not limited to): to gain foresight, interest, size of graphic, matching information between prose and graphic, to think about the content, and to get another look or to study the graphic. After this initial coding stage, I looked for similarities and differences between and among codes. I also made theoretical comparisons, in which I compared codes specifically to Hegarty and colleagues' (1991) report of why students might navigate to and from graphics. By analyzing the codes in such ways, I was able to form categories with more refined and precise representations of students' reasons why they looked at graphics while reading (Corbin & Strauss, 2008). I validated the categories by comparing them against raw data (Corbin & Strauss, 2008).

I tested my reliability in identifying categories within students' responses with a colleague who also followed the coding scheme. We first reviewed the coding scheme together and coded 5 students' responses with discussion and consensus. We then coded 5 students' responses to each question independently, discussed in depth our decisions and came upon a consensus coding for each response. Finally, we simultaneously but independently coded responses of the other 10 students. Inter-rater reliability for these 10 students was 87%. Discrepant coding was discussed, and agreed final codes were determined.

I also analyzed the final categories with respect to students' characteristics. I did so by t-tests and crosstabs with Fisher's exact statistical calculations. These analyses provided additional information for a general description of students' prose-graphic engagement. The categories were also used in describing instances of attention during the reading process.

Describing Instances of Attention: Popular and Instructionally Complementary Instances: Instead of individually analyzing each instance of attention that occurred among the 20 students, I focused on instances when most students did, and when most should have, engaged with the graphics. I called these sets of instances popular and instructionally complementary instances, respectively.

I analyzed popular instances because any instance of attention to a graphic during reading is an opportunity for informational accessibility and possible support for comprehension. The popular instances were determined by students' attention frequencies for each graphic. For the popular instances I used content analysis to analyze students' comments around each instance and to identify affordances and features of the text that made the instances popular.

I also explored instructionally complementary instances because theoretically, what we as educators would like to see, is students engaging with the graphics as they read and engage with prose at instances where instructionally the representations are complementary. Instructionally complementary instances were determined as instances where the prose and graphics together communicated instructional information. The instances were determined based on the text analysis, specifically regarding the identification of prose-graphic relationships with respect to the instructional ideas in the text. Recall that the text analysis method included organizing the information in the prose and graphics as incompatible or complementary with each representation. I used the students' maps to determine whether students used the graphics before and/or at the instructionally complementary instances.

I first explored how students' frequencies of attention at the instances compared with respect to the students individually, by their reading achievement and prior knowledge. I also analyzed students' think-aloud comments at each complementary instance by constant comparative method with grounded theory. I did so to discern patterns and identify ways the students who used the graphic at an instructionally complementary instance might have engaged with the prose and graphics versus how students who did not use the graphics might have engaged with the prose at the instance. I also identified how students' engagement with the texts and their individual characteristics interacted with respect to the affordances, features and limitations of the prose and graphics.

The Interview in its Entirety: Themes about Students' Prose-Graphic Engagement Represented Throughout

To identify mechanisms behind students' prose-graphic engagement I also focused on students' engagement throughout their entire reading and sense making processes (Table 3.14). This included students' pre-reading responses; think-aloud comments while reading; and post-reading responses (to stimulated recall, metacognitive and interest questions). I therefore used constant comparison – grounded theory (Strauss & Corbin, 1990) with the goal of identifying themes of students prose-graphic engagement that might explain and/or provide constructs toward the mechanism of reading and making sense of texts that entail prose and graphics.

Table 3.14. Foci and Analytic Method for the Interview in its Entirety

Foci of Analyses	Analytic Method
Themes about Prose-Graphic Engagement Represented Throughout the Interview	Constant Comparison Grounded Theory

I first read through interviews in their entirety and compared interviews by open coding. I looked for key issues, recurrent events or activities found within across individuals' reading and sense making processes. In the second stage of coding, axial coding, I looked for connections between codes. In this step I also identified codes related to theoretical factors that can influence students' reading, comprehension, and possibly prose-graphic engagement. For example, codes related to students' interest involved comments on interest of the text and/or graphics; features within prose and/or graphics that relate to the real-world (i.e., the realm of practical or actual experience); and references to prior experiences. Other codes related to prior knowledge of science content, inclusion of the word "molecule" and comments concerning visualization of molecules described in the texts. I also identified codes related to students' possible confusion and/or difficulty with the texts.

I then focused on the theoretical constructs and tested the codes within each via selective coding. I created tables for each category, organizing together the coded instances across data sources (e.g., across each interview and across each student). I also wrote about each category in attempt to create themes. These themes accounted for the information I collected for each category. Also within the tables for each category I wrote interpretive commentary, in which I explained the context of each example and how the examples confirm (or disconfirm) themes and assertions.

I also wrote short theoretical memos about each category and the themes, linking identified patterns to relevant literature. Through this iterative process of sorting through data, reorganizing tables with exemplars of themes, writing interpretive commentaries and theoretical memos, one specific category emerged as integral to the students' engagement with the prose and graphics: connective features.[12] In the results chapter I focus on the contexts and themes about students' prose-graphic engagement with regard to connective features in (and not in) the graphics.

SUMMARY OF METHODS AND DATA

I conducted a descriptive study about sixth graders' prose-graphic engagement as they read and made sense of two chemistry texts. I interviewed 20 students. The interviews involved students' reading the two texts aloud with a think-aloud protocol, as well as their responses to interest and metacognitive questions about the texts and their reading of the texts. By pre-interview tasks and the interviews I collected and analyzed three sets of data: (1) data on students' individual characteristics (each student's

[12] What I call connective features have been, in literature, called contextualization and/or contextual elements (see Chapter 2 and, in this chapter, Step 5: Analysis of Texts). Connective features in graphics are realistic depictions (also called real-world examples) that encompass two types of "connections": (1) The first involves a connection with students' lives (i.e., examples that students most likely have directly or indirectly experienced). Note with this connection, the reader is the one who will in the end make connections among his/her experiences with the text features, his/her self, and his/her experiences with the world. (2) The second entails intertextual links (i.e., connections between real situations and science ideas surrounding the situations, and relationships between the real everyday and the abstract scientific).

integrated reading achievement, prior knowledge and interests); (2) data on the science texts they read; and (3) data on students' prose-graphic engagement with the texts.

The set of data on students' individual characteristics was reduced and is reported in Chapter 4. Chapter 5 entails the results of analyzing the texts. In Chapter 6 I report findings from analysis about the third data set, with respect to the information gained from identifying students' individual characteristics and characteristics of the texts. In Chapter 6 I therefore discuss patterns that emerged in efforts to characterize students' prose-graphic engagement with the texts, taking into consideration students' reading achievement, prior knowledge, and interests, as well as characteristics of the texts.

CHAPTER 4
REPORT OF STUDENTS' CHARACTERISTICS

In this chapter I discuss characteristics of the students in this study. Data on the students as individuals support the research question and specifically address focal question 2: *How do characteristics of each reader interact with how he/she engages with prose and graphics when reading and making sense of the texts?* I used the findings about students' characteristics as I analyzed their engagement with the texts. This included using the characteristics to consider each student individually, as well to compare among groups of students. I address the following characteristics: integrated reading achievement, prior knowledge, and interest in the texts and graphics.

INTEGRATED READING ACHIEVEMENT

In characterizing students' integrated reading achievement I took into account each student's performance on the SARA reading diagnostic and his/her comprehension of the *Bitter Blockers* and *Cooking with Ovens* texts. Students' performances on the SARA reading diagnostic were described in Chapter 3. Below I report assessment of students' comprehension of the two texts. Then I describe the integration of these two assessments to determine students' integrated reading achievement.

Comprehension of *Cooking with Ovens* and *Bitter Blockers*

Recall from Chapter 3 that students' comprehension of each text mainly involved their scores from the comprehension questions. A student comprehended a text at higher level if he/she scored 80% or above; he/she comprehended, but at a medial level, if he/she scored between 50% and 80%; and he/she failed to comprehend if he/she scored under 50%. I also used students' retelling ideas to support assessment of their comprehension, and to assess those who scored 50% as either comprehending at the medial level or not comprehending the text. Table 4.1 shows students' scores and percentage retold ideas, organized by the number of texts they comprehended. A group of 6 students comprehended neither text, 2 students comprehended one of the two texts, and most students (12) comprehended both texts.[13]

Table 4.1: Comprehension of the Texts

Text Comprehension and Student	Cooking with Ovens		Bitter Blockers	
	Comprehension Score %	Recall % [A]	Comprehension Score %	Recall % [A]
Comprehended Neither Text				
Dana	25	11	50	5
Fran	30	17	50	8
Haiden	30	17	30	13
Jessie	30	17	10	5
Layne	30	28	10	18
Macy	50	30	40	18
Comprehended One Text				
Blair	90	26	30	10
Vaan	50	13	90	35
Comprehended Both Texts				
Walei	50	37	70	8
Xipil	60	30	50	40
Casey	70	22	60	33
Garnet	70	20	60	28
Rene	70	37	70	18
Patel	70	26	80	25
Kris	60	30	80	10
Zavit	90	26	50	45
Sam	100	39	60	20
Quinn	90	33	60	25
Neci	60	41	90	43
Terri	70	15	90	25

A: Percentage (%) is of total possible ideas (46 total for *Cooking with Ovens*; 40 total for *Bitter Blockers*)

[13] The table does not show the percentage of ideas *mapped* to each comprehension question, nor does it show my use of questions regarding students' retold ideas (e.g., "Is the recall accurate?" and "Did it further support the comprehension questions?"). These were also factors that supported assessment of readers' comprehension level. Descriptions of my assessment with respect to these factors are in Appendix I.

Determining Integrated Reading Achievement

I integrated each student's pre-interview reading level (based on the SARA diagnostic) and comprehension level for both texts to determine his/her integrated reading achievement. Table 4.2 shows students' levels according to their integrated reading achievement. As the table shows, I categorized students as struggling, intermediate or proficient readers.

Table 4.2: Integrated Reading Achievement

Integrated Reading Achievement Group and Student	SARA Pre-interview Reading Group	Comprehension Level	
		Cooking with Ovens	*Bitter Blockers*
Struggling			
Blair	Low	Higher	X
Dana	Low	X	X
Fran	Low	X	X
Haiden	Medium-Low	X	X
Jessie	Medium-Low	X	X
Layne	Medium-Low	X	X
Macy	Medium-Low	X	X
Intermediate			
Casey	Low	Medial	Medial
Garnet	Low	Medial	Medial
Rene	Medium-High	Medial	Medial
Vaan	High	X	Higher
Walei	High	Medial	Medial
Xipil	High	Medial	Medial
Proficient			
Kris	Medium-Low	Medial	Higher
Neci	Medium-High	Medial	Higher
Patel	Medium-High	Medial	Higher
Quinn	Medium-High	Higher	Medial
Sam	Medium-High	Higher	Medial
Terri	High	Medial	Higher
Zavit	High	Medial	Higher

A: X = no comprehension

Students were considered *struggling* readers if they were either low or medium-low readers from the SARA diagnostic and if they failed to comprehend one or both texts. In this way a *struggling* reader pertained to any student who showed signs of difficulty in both assessments. This included Blair, the only struggling reader to comprehend one of the science texts. All others failed to comprehend both texts.

Students were considered *proficient* readers if they were in the medium to high groups based on the SARA diagnostic, if they comprehended both texts, and if they comprehended at a higher level for one text. Of the seven proficient readers, four were in the medium-high group from the SARA diagnostic assessment, and one was in the medium-low group.[14] Although these readers in the medium SARA groups demonstrated difficulty in providing the main idea of the SARA texts, their comprehension of the texts in this study, and their comprehension at a higher level for one of the texts, demonstrated their proficiency in reading science texts.

All other students were considered *intermediate* in that their performances showed some signs of proficiency and some signs of struggle when performing the SARA diagnostic and/or when reading science texts in this study. Most of the intermediate readers comprehended both texts, yet their scores were at the medial level. For example, Xipil's performance on the SARA suggested that she was a proficient reader. She read the SARA texts fluently, with few errors, and scored an average of a three for identifying the main ideas (Tables 3.4 and 3.5). However, her comprehension scores for both texts were at the medial level (Table 4.1). Or, as in Vaan's case, a student could have been assessed as a high reader from the SARA diagnostic, and even comprehended a text at the medial level, but failed to comprehend the other text. Xipil's and Vaan's scores suggest they may be in between those students who consistently struggled in their reading of science texts and those who were more consistently proficient.

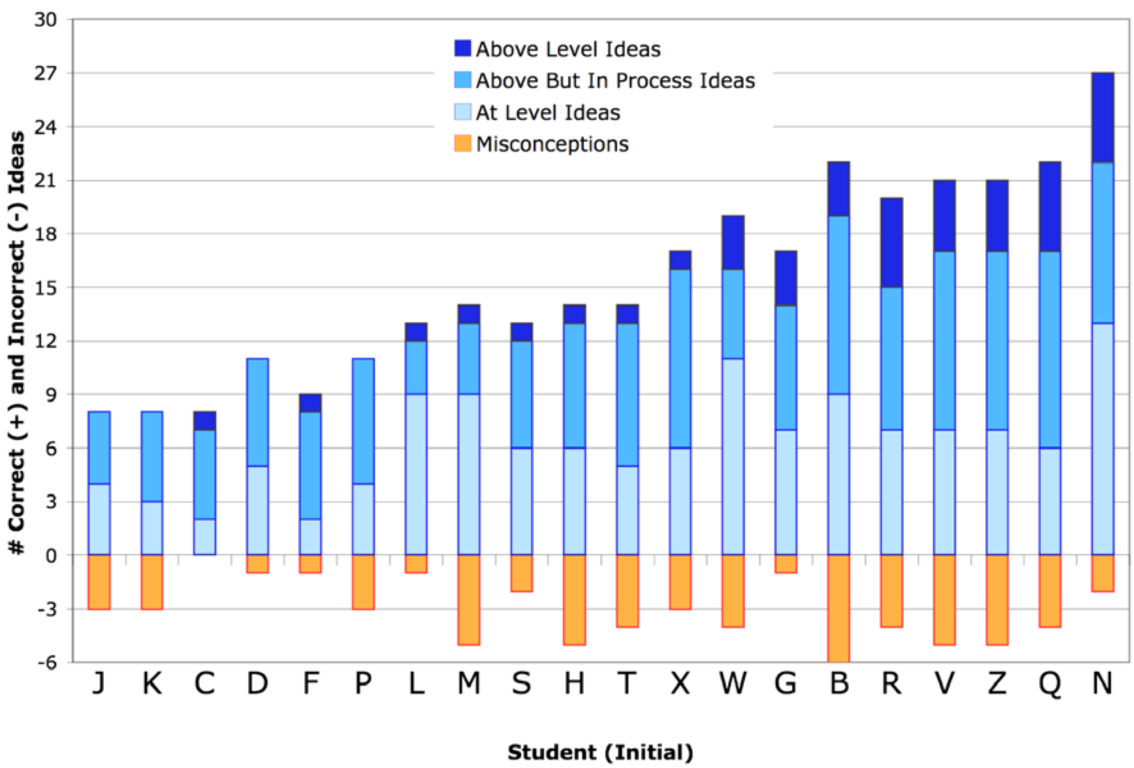
[14] Note in Table 4.2 that Kris is the only proficient reader who was in a lower SARA group. Kris was one of those students who did not clearly fit into the medium-low or medium-high groups. His fluency and low number of errors suggested proficiency: Kris had the fewest average reading errors, highest average speed, and the least word recognition errors in the medium-low group. All these measures together would have placed Kris in the medium-high or high groups. Yet Kris's main idea scores showed he had difficulty in identifying the main idea of the texts, especially with the one science text in the SARA diagnostic. Due his comprehension scores of both the Cooking with Ovens and Bitter Blocker texts, I chose to characterize Kris as a proficient reader.

I used the integrated reading achievement groups as I analyzed students' engagement with the texts. As described in subsequent chapters, I used this characteristic as a way to compare students with respect to various facets of their prose-graphic engagement as they read and made sense of the science texts.

PRIOR KNOWLEDGE

I applied students' overall prior knowledge to descriptions of prose-graphic that involved both texts. Figure 4.1 shows each student's total number of correct and incorrect ideas across the three science content areas (molecules; tasting and taste buds; microwaves and microwave ovens). The positive columns highlight the total number of correct ideas. The three shades identify the level of each stated idea – at level (lightest shade towards the bottom), above but in process (meaning students were in the process of learning the ideas; medium shade in the middle), and above level (darkest shade on top). The negative shade reflects the number of misconceptions stated.

***Figure 4.1*. Overall Prior Knowledge: Total Number of Ideas**



For example, Neci (N) provided 27 accurate ideas about the three content areas. Of these ideas, 5 were above level, 9 were above but in process, and 13 were at level. Neci also provided two misconceptions.

In Figure 4.1 students are ordered with respect to their weighted score. I counted and calculated weighted values to follow the perspective described in subsequent chapters that knowledge may be presented in pieces, and that the quantity and quality of ideas stated demonstrates students' prior knowledge. I therefore weighted the values to reflect more contribution for above level and above but in process levels. Each above level ideas was a value of four, each above but in process idea was a value of two, and each at level idea was a value of one. This is why, for example, Rene (R) is to the right of Blair (B). Even though Blair provided more ideas, Rene's weighted score was higher than Blair's because Rene provided more above level ideas.

Together the students articulated on average six at level ideas, seven above but in process ideas, two above level ideas, and three misconceptions. The average weighted value for correct ideas stated was 29 (+/-12), and the median was 24.5 (with the lowest value of 12 and the highest values of 51).

Determining Overall Prior Knowledge

I assessed each student's overall prior knowledge as low, average or high, based on the students' weighted values.[15] I first utilized any natural divisions among students' weighted values. One such division existed for the students with higher prior knowledge, between Garnet (G) (whose weighted value was 33) and Blair (B) (whose weighted value was 41). The weighted value difference between the two was 8. This difference reflects inclusion of two more above level ideas or eight more at level ideas (or a combination of the two). Therefore I placed all students with values at or beyond 41 into the high prior knowledge group. This includes six students; Blair and the other five students to the right of Blair (Figure 4.1; Rene, Vaan, Zavit, Quinn and Neci). The boundary of 41 to indicate high prior knowledge is also in agreement with one standard deviation from the mean weighted value.

[15] I recognize this process provides relative levels of low, average and high because the levels are based only on the 20 students in this study.

No other natural division appeared with respect to weighted values. I therefore used the mean and standard deviation of weighted values, as well as patterns in students' inclusion of above level ideas, to determine low and average prior knowledge limits. Students were determined to have low prior knowledge if their weighted values were 17 (the average minus standard deviation) or less. This includes the five left-most students in Figure 4.1 (Jessie, Kris, Casey, Dana, Fran). Notice in Figure 4.1 that Casey and Fran are students who articulated few ideas, but provided one above level idea. These students were considered as having lower prior knowledge. Even though the student provided an idea that falls in a higher level, the student's responses to the prior knowledge questions were not as robust to consider the student's knowledge as cohesive.

Although Patel (P) included enough ideas to have a weighted value of 18, she failed to include any above level idea. Also, the amount and type of ideas Patel included seems more similar to the students with low prior knowledge (i.e., Dana) than the average prior knowledge counterparts. Therefore I also assessed Patel as having low prior knowledge.

The students, therefore, who had weighted values from 18 to 33, *and* who articulated at least one above level idea, were assessed as having average prior knowledge. This included all students in Figure 4.1 from Layne (L) to Garnet (G). As an example, notice that the number of correct ideas Walei articulated seems to suggest a higher prior knowledge (Figure 4.1). Yet more than half of those ideas were at level. The level and number of ideas Walei provided suggests his ideas are more robust. Yet others provided even more ideas at the various levels, which relatively, suggested Walei's average prior knowledge as average.

I used *t*-test of means to compare the integrated reading groups with respect to their mean overall prior knowledge scores. The *t*-test failed to reveal a statistically reliable difference between the mean scores of each integrated reading group. The lack of significance in the t-tests suggests that the integrated reading achievement groups *on average* were not different from each other with respect to students' overall prior knowledge.

Prior Knowledge of Content Areas

I used students' prior knowledge of the individual content areas (molecules, tasting and taste buds, and microwaves and ovens) to describe students' engagement at specific instances, and therefore with specific texts. I assessed students' prior knowledge levels for each content area the same way that I determined their overall prior knowledge. Table 4.3 summarizes each student's prior knowledge levels overall and by content. Following, I briefly report the results and placement of students into groups.

Table 4.3. Summary of Prior Knowledge by Reading Achievement

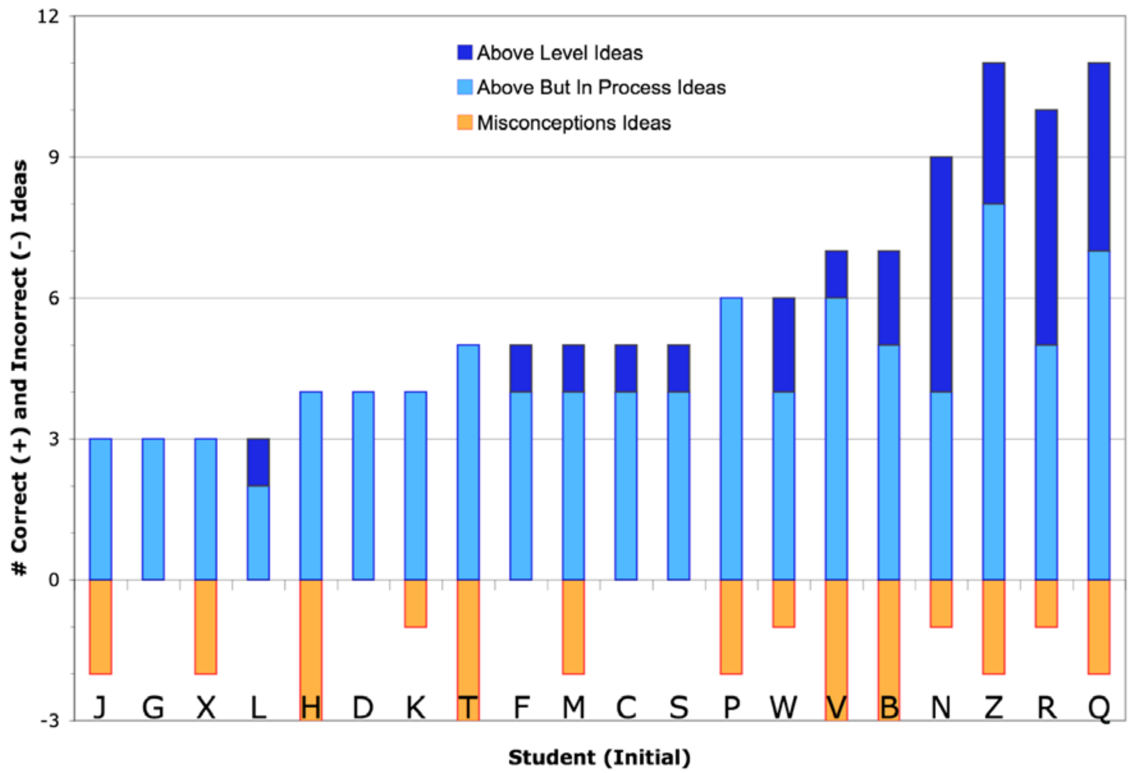
Integrated Reading Achievement Group & Student	Prior Knowledge			
	Overall	Molecules	Microwaves & Ovens	Tasting & Taste Buds
Struggling				
Jessie	low	lower-average	low	low
Dana	low	lower-average	low	average
Fran	low	average	low	low
Layne	average	lower-average	low	average
Haiden	average	lower-average	low	high
Macy	average	average	low	average
Blair	high	high	average	high
Intermediate				
Casey	low	average	low	low
Garnet	average	lower-average	high	high
Xipil	average	lower-average	high	average
Rene	high	high	average	average
Walei	average	high	average	average
Vaan	high	high	high	high
Proficient				
Kris	low	lower-average	low	low
Patel	low	average	low	low
Terri	average	lower-average	average	high
Sam	average	average	average	low
Neci	high	high	average	high
Quinn	high	high	high	average
Zavit	high	high	low	high

Prior Knowledge – Molecules

Recall from Chapter 3 that the pre-reading questions asked a general open-ended question about molecules, whereas the pretest included items that addressed the particulate nature of matter and kinetic molecular theory. Therefore by using both the pretest and interview questions I obtained a more complete understanding of students' knowledge of molecules.

Assessment Via Interview Pre-Reading Questions: Figure 4.2 depicts the number of correct and incorrect ideas students articulated with respect to their prior knowledge of molecules. For this content area, the 20 students articulated on average four *above but in process* ideas, one *above average* idea, and one misconception.

Figure 4.2. **Prior Knowledge of Molecules**



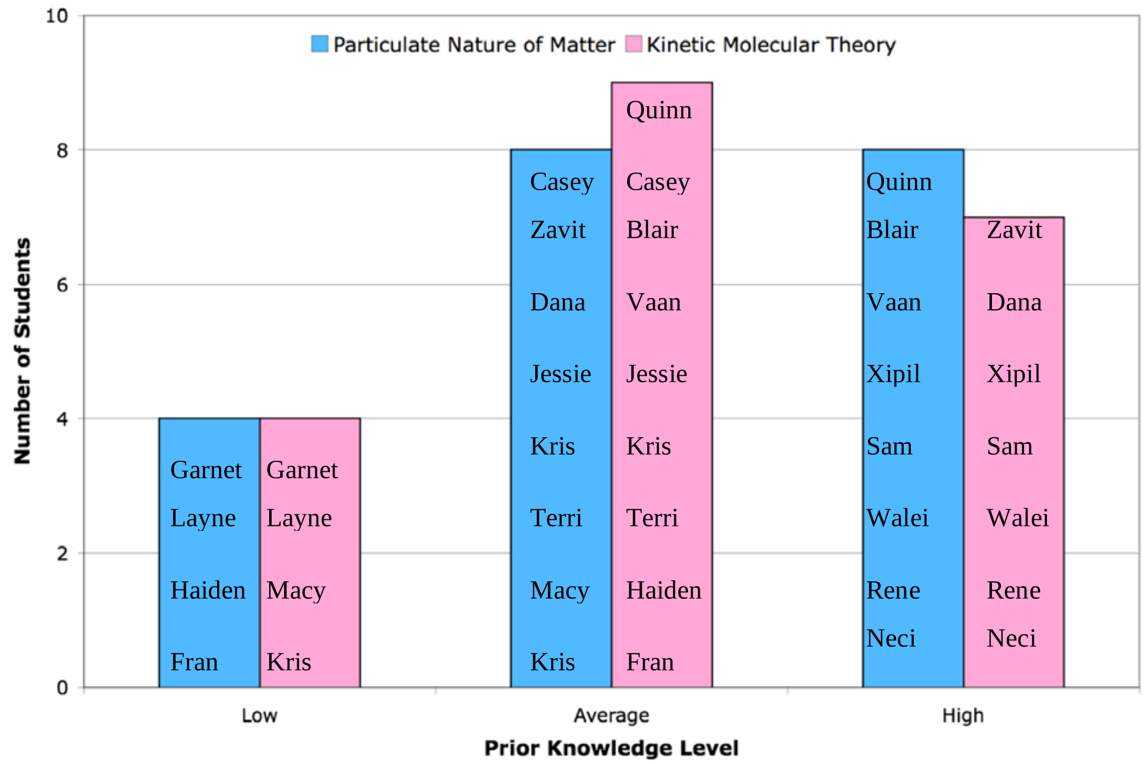
Notice that no student provided *at level* ideas for molecules. This is because the concepts of molecules – that is, the particulate nature of matter and kinetic molecular theory – appear in grades 6-8 in the Atlas and Benchmarks. At the time of this study the students just began instruction about molecules for the sixth grade. Therefore the fact that all students provided *in process level* ideas is an indication that all the students had some knowledge about molecules which was above their level.

Of the students who talked about *above level* ideas, only Neci, Quinn and Rene's responses included ideas that molecules change by movement and/or spacing according to temperature. Knowledge of these ideas is a learning goal within the *Smell* unit, and within the *Cooking with Ovens* text. Neci described the relative speed of molecules when food is hot/cold. Quinn, on the other hand, knew molecules change according to temperature, but was not coherent in explaining the way the molecules change. And Rene described the change in spacing between molecules as temperature changes, but did not touch on the movement of those molecules. Other students articulated *above level* ideas that were not directly related to the texts, and included the following notions: molecules are made up of atoms; certain molecules consist of different atoms; the spacing of molecules relative to the physical states of matter; and the use of chemical formulae.

Assessment Via Pretest Items: As described in Chapter 3, pretest scores were calculated for each student on items that reflected knowledge about matter being made of molecules (particle nature of matter) and items that dealt with movement of those particles with respect to temperature (kinetic molecular theory). I report the scores as separated components because the interview pre-reading questions focused on molecules, but did not specifically address students' knowledge about movement of the molecules. I therefore used students' performances with the pretest to better understand students' prior knowledge about molecules' movement with respect to temperature.

For the pretest students were assessed as low, average, and high, by comparing individual scores to the average score of the entire dataset (N=50). Figure 4.3 illustrates the number and names of students whose scores indicated low, average and high prior knowledge for both the particle nature of matter and kinetic molecular theory.

***Figure 4.3.* Prior Knowledge of the Particulate Nature of Matter and Kinetic Molecular Theory via Pretest**



Determining Prior Knowledge of Molecules: Assessing students' prior knowledge of molecules was mostly based on their responses to the interview questions, but also guided by the pretest levels. The seven right-most students in Figure 4.2 (from Walei to Quinn) were assessed as having high prior knowledge. These students articulated more ideas (and more *above level* ideas) than the other students. Also, these students scored above average for the pretest items about the particle nature of matter and/or kinetic molecular theory.

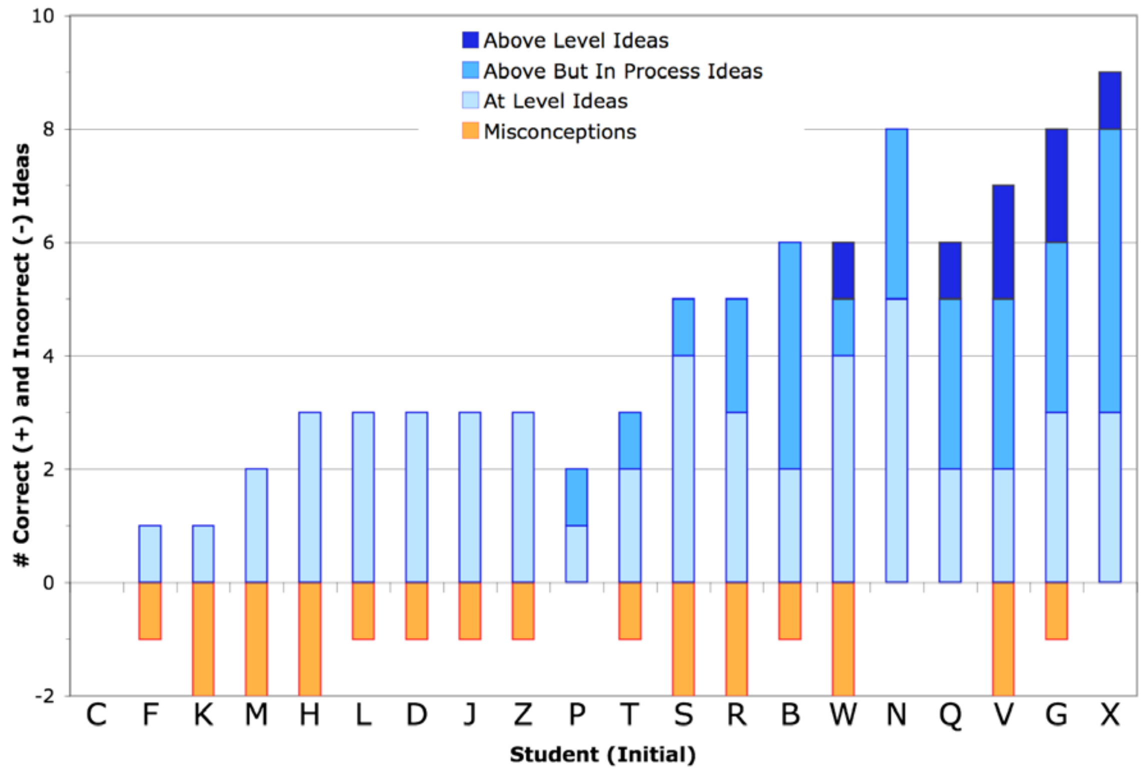
The other 13 students were separated into two groups: *lower-average* and *average*. Recall that each student provided at least three *above but in process level* ideas in his/her responses. Therefore even the students who articulated few ideas showed they have knowledge above their level, and should not be considered as having low prior knowledge. This includes Xipil, Jessie and Garnet; the three students who articulated the least number of ideas. These students articulated ideas such as the size of molecules (that they are really small; that one cannot see molecules), a general notion of everything being made of molecules, and stating specific objects that are made of molecules (e.g., one's body, the desk, air, shampoo, liquids). These ideas suggest that Xipil, Jessie and Garnet were not lower than they should be by the sixth grade level. On the contrary, the ideas they articulated show they were *in the process* of learning about molecules and knew some things about molecules, even though the knowledge was not a very complete and cohesive set of ideas. I also made the groups to account for some students, like Xipil, who demonstrated lower prior knowledge in the interview yet demonstrated higher prior knowledge in the pretest (Figures 4.2 and 4.3), and other students who provided some above level ideas.

The eight left-most students in Figure 4.2 (from Jessie to Terri) were therefore assessed as having lower-average prior knowledge of molecules. These students, except Layne, provided *in process level* ideas, yet failed to include *above level* ideas. The other five students (Fran, Macy, Casey, Sam and Patel) articulated at least one *above level* idea, and were therefore considered as having average prior knowledge of molecules.

Prior Knowledge – Microwaves and Ovens

I also assessed students' prior knowledge of the texts' context. Figure 4.4 shows the number of correct and incorrect statements students portrayed in their responses about microwaves and ovens – the content in *Cooking with Ovens*. For this content area, the 20 students articulated on average three at level ideas; one above but in process idea; no above average ideas; and one misconception.

Figure 4.4. **Prior Knowledge of Microwaves and Ovens**



The four right-most students in Figure 4.4 were considered as having high prior-knowledge of microwaves and ovens. The 10 left-most students in Figure 4.4 (from Casey to Patel) were considered as having low prior knowledge, based on their similar pattern of including only three or less *at level* ideas. Patel was the only one of the students in the low group who also articulated an *above but in process level* idea. Yet Patel's articulation of only two total correct ideas about microwaves and ovens suggests the extent of her prior knowledge as relatively low.

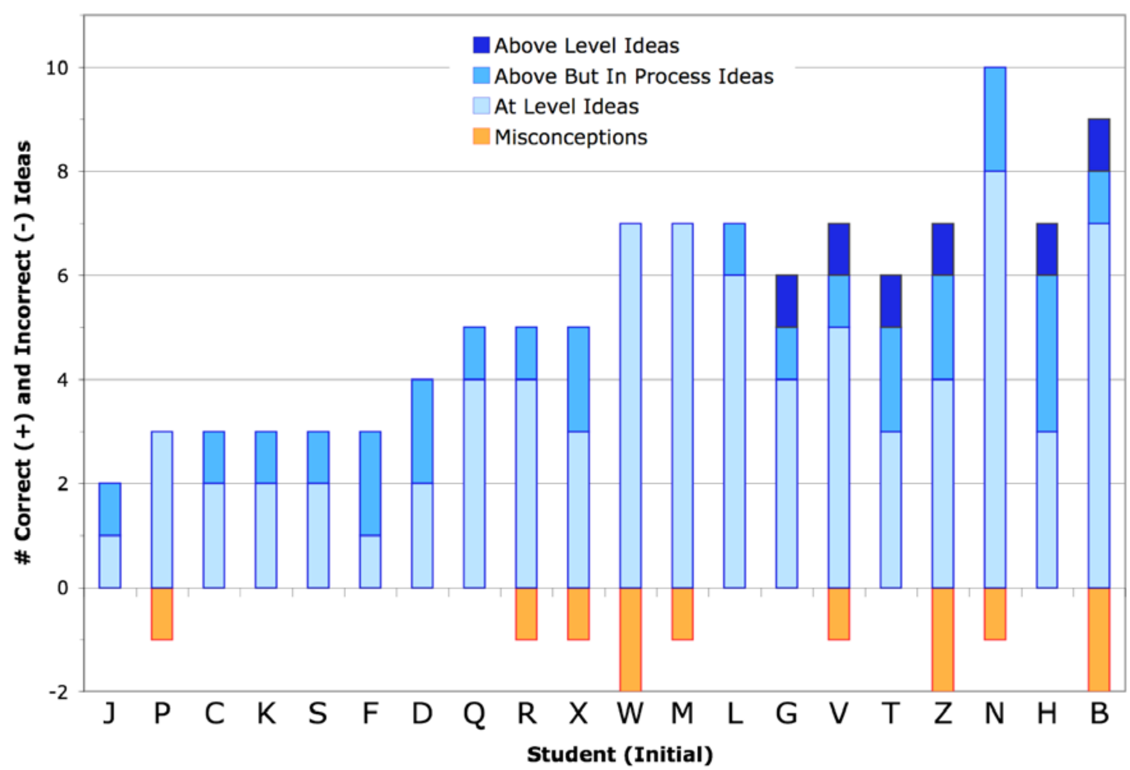
The middle six students, from Terri (T) to Neci (N) were determined as having average prior knowledge about microwaves and ovens. Although Neci articulated many ideas about the topic, he articulated eight total ideas (most of which were at level) and failed to provide any above level ideas. In this way the pattern of Neci's ideas is more similar to the other average prior knowledge students.

<u>*Prior Knowledge – Tasting and Taste Buds*</u>

Figure 4.7 represents the number of correct and incorrect statements students portrayed in their responses, this time about tasting and taste buds. Two of the most commonly stated *at level* ideas was taste buds or a type of sensor (when asked how we taste), and that taste buds are located on the tongue (when asked to tell about taste buds). Two *above level* ideas about taste buds and tasting that students included were: that taste buds detect atoms/molecules, and that each type of taste bud interacts with a different type of molecule.

Similar to assessment on prior knowledge of microwaves and ovens, the 20 students articulated few ideas about tasting and taste buds. On average students articulated four at level ideas; one above but in process idea; no above average ideas; and one misconception.

***Figure 4.5.* Prior Knowledge of Tasting and Taste Buds**



The six left-most students in Figure 4.5 (from Jessie to Fran), considered as having low prior knowledge of tasting and taste buds, articulated up to three total *at level* and/or *above but in process level,* ideas. Students considered as having high prior knowledge of tasting and taste buds were the seven right-most students in Figure 4.5 (students Garnet through Blair). These students, except Neci, provided an *above level* idea about tasting and taste buds. These ideas dealt with tasting at the molecular scale, which also map directly to the content and learning goals of the Bitter Blocker text.

The seven middle students, from Dana to Layne (Figure 4.5), were therefore identified as having average prior knowledge of tasting and taste buds. These students with average prior knowledge tended to provide multiple *at level* and *in process* level ideas about tasting and taste buds.

Summary of Prior Knowledge

In this section I characterized students' overall prior knowledge and identified students' prior knowledge levels for each content area (molecules, tasting and taste buds, and microwaves and ovens). In summary, students in each integrated reading achievement group represent various levels of prior knowledge (Table 4.3). I used the overall prior knowledge when analyzing students' prose-graphic engagement regarding both texts. I used prior knowledge of the three individual content areas when analyzing students' engagement with the specific texts. Emergent patterns with respect to prior knowledge are described in Chapter 6.

INTEREST

As part of the pre-reading task I asked students to rate their interest in reading each text on a scale of one to five (one being the least interested and five being the most interested). I also asked students about their interest in each text and each graphic after they read the texts. I reduced the data into three modes: indifferent (e.g., "not really interested"), interested (e.g., "sort of" or "a little interested") and very interested (e.g., "I was really interested…").[16]

Figures 4.6 and 4.7 show the number of students per level of interest for the pre-reading and post-reading tasks, respectively. The figures show that most students were

[16] For the pre-reading ratings, this meant recoding responses of 1 and 2 as indifferent, 3 and 4 as interested, and 5 as very interested. I coded students' post-reading interests based on their comments about the text and/or graphics.

generally interested in the texts before and after reading. Minimal changes in the number of interested students occurred from pre-reading to post-reading as six students became *more interested* in a text (four went from interested to very interested in a text, two went from indifferent to interested), whereas two students became *less interested* in a text, after reading. Even with the changes in interest that occurred from before to after reading, most students continued to articulate interest in the texts after reading. Because a majority of students were interested in the texts both before and after reading, and because few were very interested or indifferent to the texts, I focus on the few students with a lot or little interest. These students are named in the figures.

Figure 4.6. **Pre-reading: Number of Students per Level of Interest for Each Text**

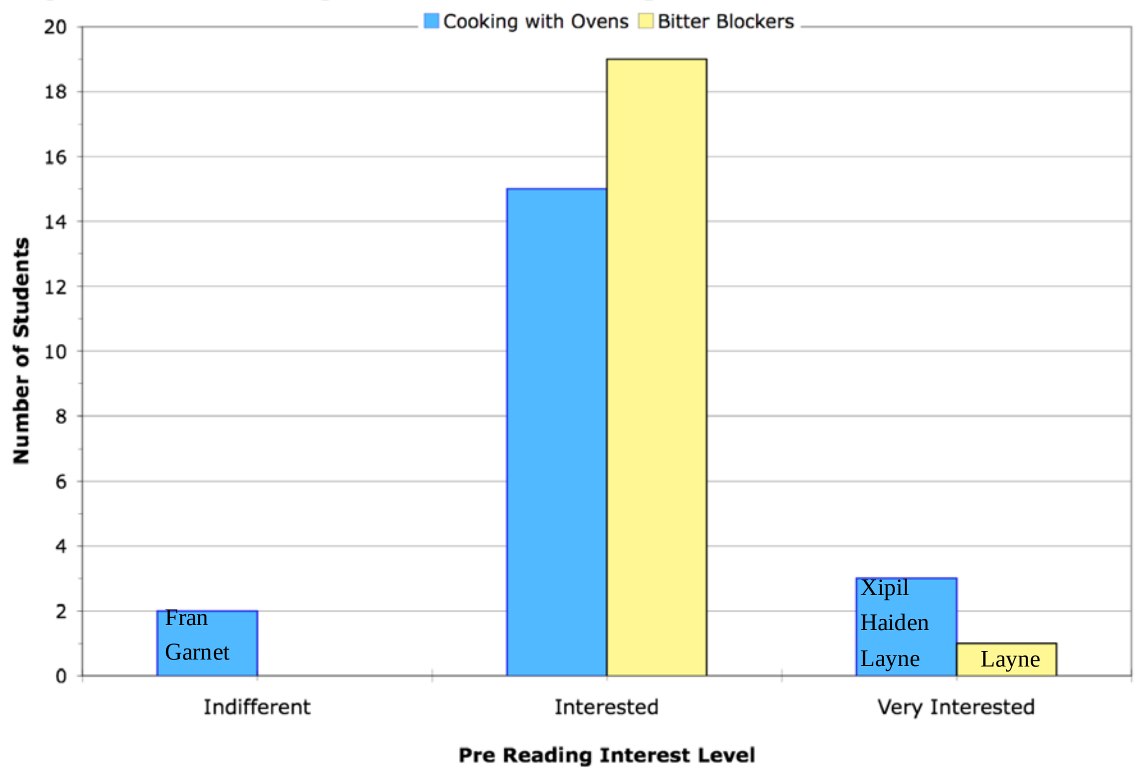
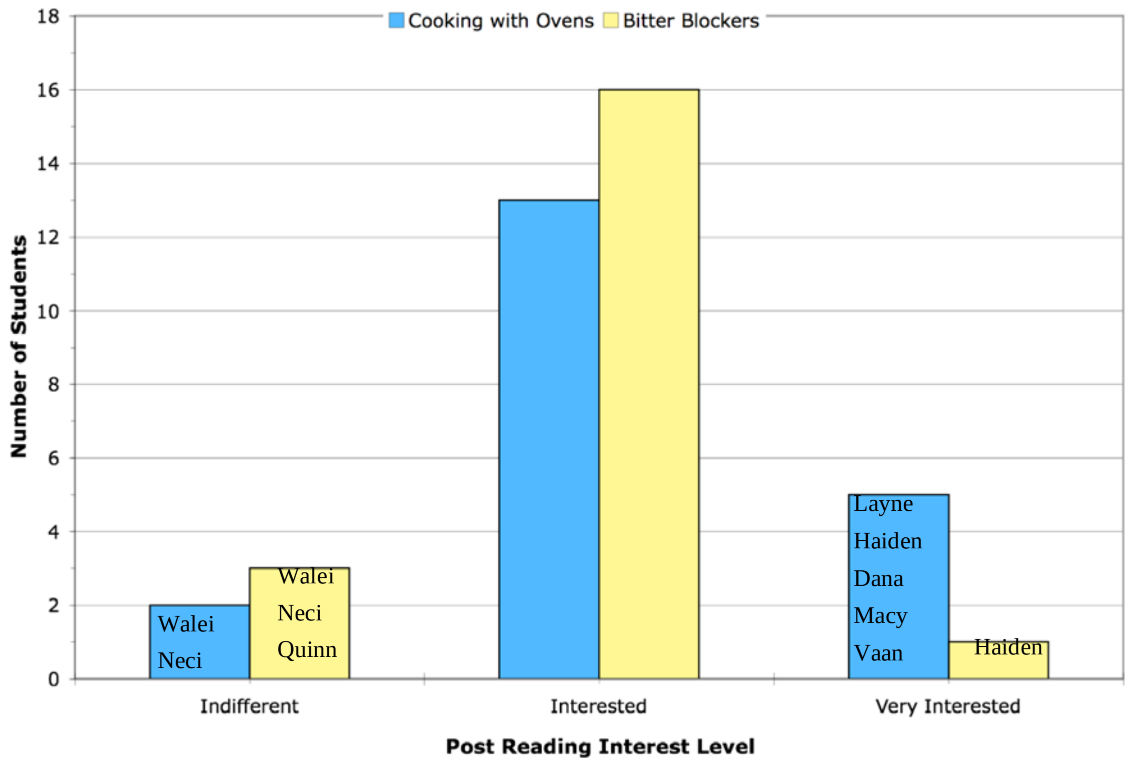
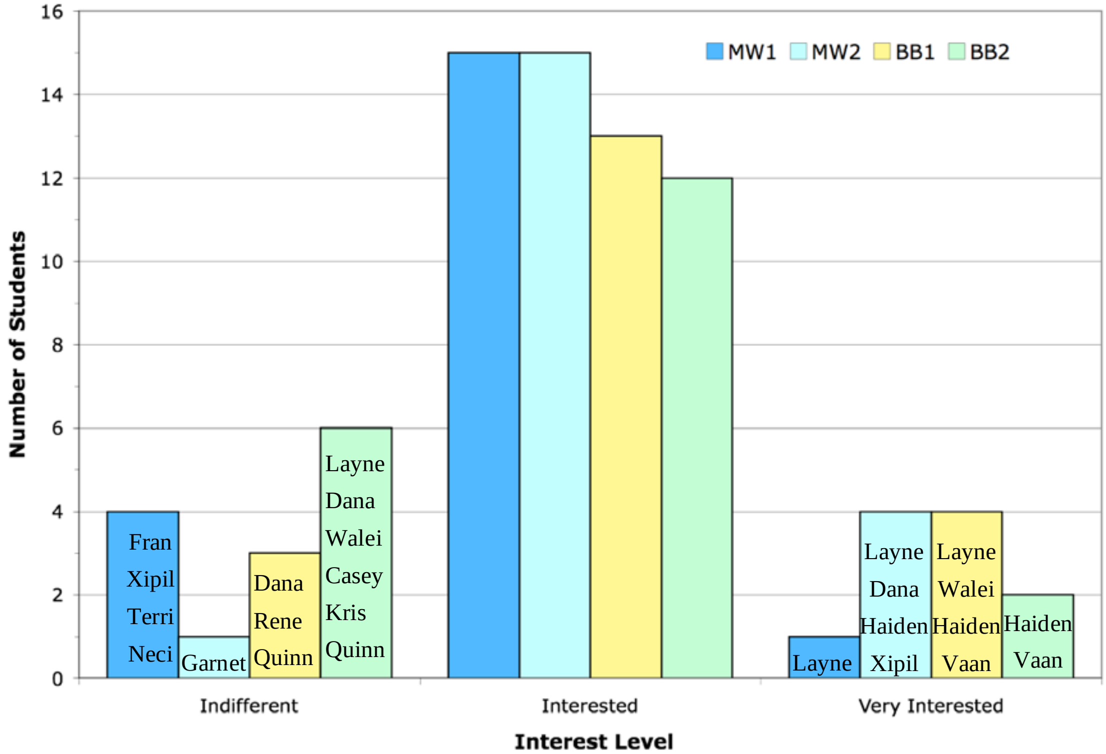


Figure 4.7. **Post-reading: Number of Students per Level of Interest for Each Text**



I also looked at the level of students' interests toward each graphic. Figure 4.8 details the number of students per interest level for the graphics in each text. Most students were interested in each graphic. MW2 was interesting or very interesting to the most amount of students (19), whereas BB2 was interesting, or very interesting, to the least amount of students (14). The most amount of students were very interested in graphics MW2 and BB1. Recall that these graphics were about how microwave ovens work (with an illustration of a turkey in a microwave, among other features) and how one tastes (with an illustration of a person's tongue, among other features). Of the six readers who expressed being very interested in a graphic, five had also reported high interest in a text.

Figure 4.8. **Interest Levels for Each Graphic (MW1, MW2, BB1, & BB2)**



A total of 12 students reported indifference to at least one graphic. However only 3 of those readers (Walei, Neci and Quinn) reported indifference to both a text *and* at least one corresponding graphic.

<u>Comparing Students who were either Very Interested or Indifferent</u>

Table 4.4 lists other characteristics of the readers who expressed either much interest or indifference to the texts. As Figures 4.6, 4.7 and Table 4.5 show, three of the students who were very interested in the texts before reading were struggling readers. Of the five students who were very interested post reading, four were struggling readers, and one was an intermediate reader. No proficient readers were *very interested* in the texts. In fact, a majority of proficient readers (five of seven) were interested, whereas the majority of struggling readers (four of seven) were very interested, pre- and post-reading. The relationship of levels of interest by reading achievement may interact with the ways these students engage with the text.

Table 4.4. Pre- and Post- Reading: Students who were either Very Interested or Indifferent to a Text

Interest Level & Student	Integrated Reading Achievement Level	Overall Prior Knowledge Level
Very Interested either Pre- or Post- Reading		
Layne	Struggling	Average
Haiden	Struggling	Average
Xipil	Intermediate	Average
Dana	Struggling	Low
Macy	Struggling	Average
Vaan	Intermediate	High
Indifferent either Pre- or Post- Reading		
Fran	Struggling	Low
Garnet	Intermediate	Average
Walei	Intermediate	Average
Neci	Proficient	High
Quinn	Proficient	High

I also used Tables 4.5 and 4.6 to highlight and compare characteristics of students who were very interested or indifferent to *at least one graphic*. In this case the tables are separated due to Layne, Dana, Xipil, and Walei, who reported high interest in some graphics but indifference to other graphics. Again, similar to interest in the texts, none of the students who were *very interested* in a graphic were proficient readers. Those who were very interested in a graphic also included five (of eight) students with average prior knowledge. Also, note that students who were indifferent to a graphic represent all three levels of reading achievement, as well as an almost equal amount of students from each prior knowledge level. Therefore students' general indifference to the graphics seems to relate neither to reading achievement, nor to overall prior knowledge.

Table 4.5. Students who were Very Interested in At Least One Graphic

Integrated Reading Achievement Group & Student	Overall Prior Knowledge Level
Struggling	
Dana	Low
Macy	Average
Layne	Average
Haiden	Average
Intermediate	
Xipil	Average
Walei	Average
Vaan	High

Table 4.6. Students who were Indifferent Toward At Least One Graphic

Integrated Reading Achievement Group & Student	Overall Prior Knowledge Level
Struggling	
Fran	Low
Dana	Low
Layne	Average
Intermediate	
Casey	Low
Garnet	Average
Walei	Average
Xipil	Average
Rene	High
Proficient	
Kris	Low
Terri	Average
Neci	High
Quinn	High

Summary of Students' Interest

In short, most students were at least generally interested in the texts before and after reading. Most students were also interested or very interested in the graphics. Due to the lack of variation among students, the results on students prose-graphic engagement does not include comparing among those who were indifferent, interested and very interested in the text and graphic. However one finding to note is that MW2 was most interesting to by students, followed by BB1, then MW1. BB2 was interesting to the fewest number of students. I also highlight that a large number of students were interested and/or very interested in the texts, which may relate to later descriptions of students' prose-graphic engagement (e.g., in Chapter 6 I report interest as a prominent reason why students looked at graphics).

Summary of Students' Characteristics

The goal of this chapter was to report various characteristics for each student, and to compare students grouped according to the characteristics. I used this chapter first to gain more understanding of the cases in this study. Indeed, students' characteristics do vary by individual and by groups. Also, due to the variation within groups, I did not discern any patterns of differences between groups.

I also used the assessments and characteristics together with my analyses of students' engagement with the texts to better understand the ways students use graphics when reading and making sense of the science texts. The next chapter (Chapter 5) is another analyses of characteristics, that of the texts in this study. Then, in Chapter 6, I discuss findings about students' engagement with the texts – findings that emerged based on the incorporation of analysis of students' engagement and the information on student and text characteristics.

CHAPTER 5
REPORT OF TEXTS & TEXTUAL CHARACTERISTICS

The ways students use graphics when reading a text also encompasses the text's characteristics. I therefore use this chapter to provide a rich analytical description of the *texts* used in this study. The students read these texts during my interviews with them. These texts were also the context in which I asked students about their interpretations, interests, and actions toward reading texts with graphics. The information from this analysis was used to answer the research questions and analyze students' prose-graphic engagement.

In this chapter I describe each text separately, and do so in the following manner: I first provide a visual perspective, focusing simply on the layout of each text. Then for each text I describe the structure of its prose, structure and function of the graphics, interestingness (i.e., potential interest) of the prose and graphics, and instructional ideas communicated and represented by the prose and graphics. Lastly, I summarize relationships among the prose and graphics for each text.

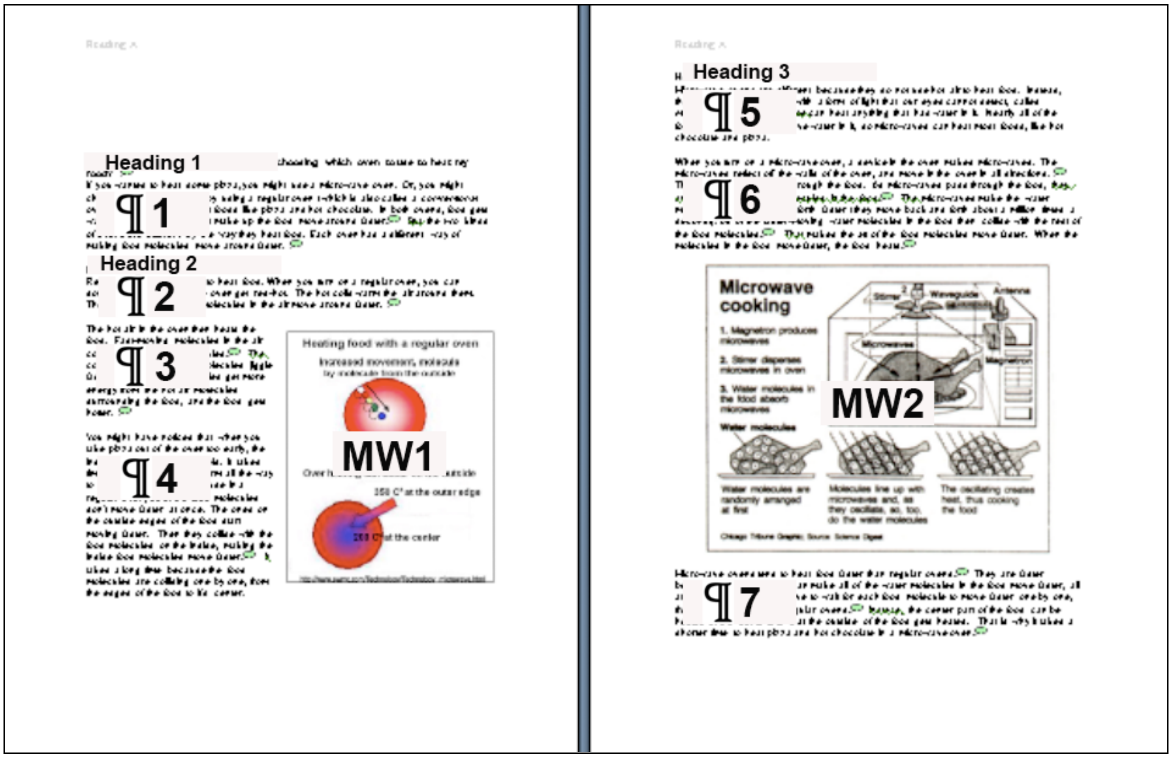
DESCRIPTION OF THE *COOKING WITH OVENS* TEXT

The *Cooking with Ovens* text was written to apply the *Smell* unit's learning goals (the particle nature of matter and the movement of molecules with respect to temperature) to a real world situation – that is, the role of molecules in warming and cooking foods. The text does this by describing how a conventional oven makes molecules move faster, versus how a microwave oven does so. The entire text is presented in Appendix A.

Visual Description of the *Cooking with Ovens* Text

The *Cooking with Ovens* text is situated on two pages lying side-by-side similar to that of a book. Within the entire text the lines of each paragraph are single-spaced, and each paragraph is separated by an empty space. Figure 5.1 shows the visual layout of the text.

***Figure 5.1.* Visual Layout of *Cooking With Ovens* Text**



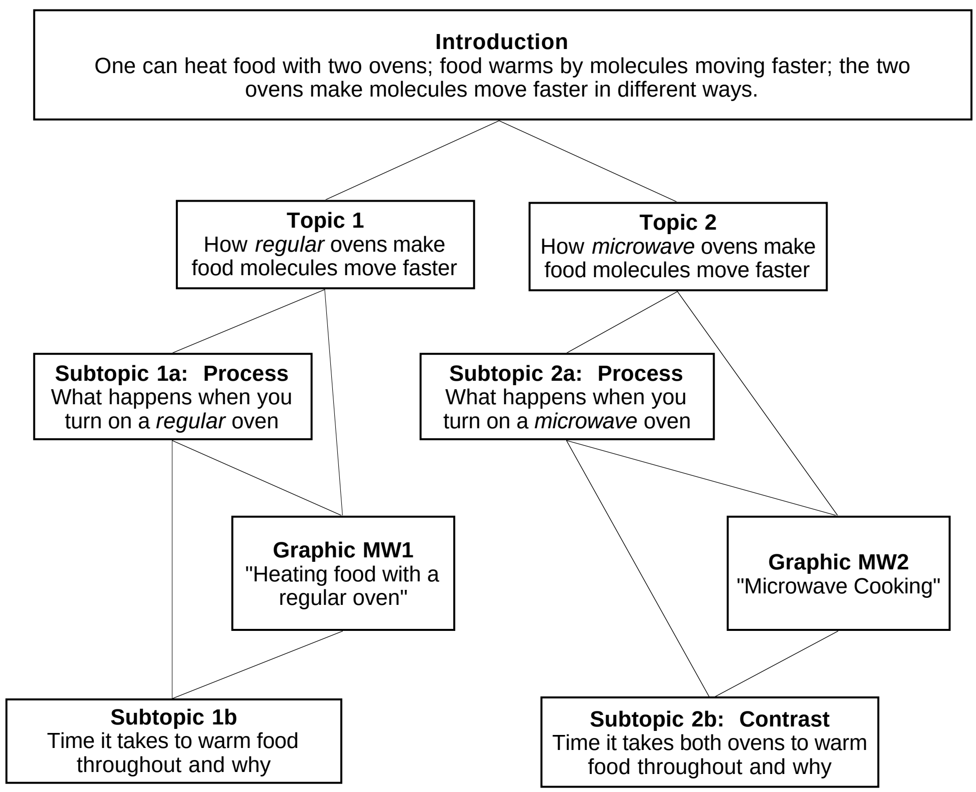
On the first page the reader would see four paragraphs, set up with two bolded headers – one before the first paragraph, and another before the second paragraph. The first two paragraphs take up the width, and about one-third of the length, of page 1. The third and fourth paragraphs are on the left half of the page, and about two-thirds the length of the page. A graphic (MW1), outlined by a box, takes the other half width of the page, to the right of the third and fourth paragraphs. The graphic is also presented in multiple colors, whereas the prose on this page is black print.

On the second page the reader would see three paragraphs (paragraphs five to seven), with one bolded header placed before the fifth paragraph. Paragraphs five and six take up the entire width and the top one-third of the page. The second graphic in the text (MW2) lies directly under paragraph 6. This graphic fills about one-half the space of the entire page length-wise and fills the width of the page. The seventh paragraph lies at the bottom of the page, under MW2, and also fills the entire width of the page and about one-fifth its length. The prose on this page is also black print, whereas the graphic MW2 is monochrome. Mainly, objects in MW2 are shaded gray and all else is outlined in black.

Structural Description of the Prose and Graphics – *Cooking with Ovens*

The global text structure of the *Cooking with Ovens* text is a comparison/contrast of two types of ovens people use to heat foods. A process/sequence structure is also embedded within the overall comparison/contrast structure, as the means of describing how each oven heats foods. Figure 5.2 represents the text's global structure (Donovan & Smolkin, 2002).

Figure 5.2. **Global Structure & Visual Diagram of Content Relationships: *Cooking with Ovens* Text**



Structure of Cooking with Ovens Prose: The prose is structured such that each of two sections focuses on one oven. These sections are parallel in that they tell first what each oven uses to heat foods; then, how the oven works to heat foods; and finally, why the oven takes a shorter/longer time to heat foods.

The entire text begins with a header, which introduces ideas that the student will read within the text, “Why should I think of molecules when choosing which oven to use to heat my food?” The first paragraph then introduces two types of ovens: microwave ovens and “regular” (conventional) ovens. This paragraph compares and contrasts the ovens with respect to how they heat foods.

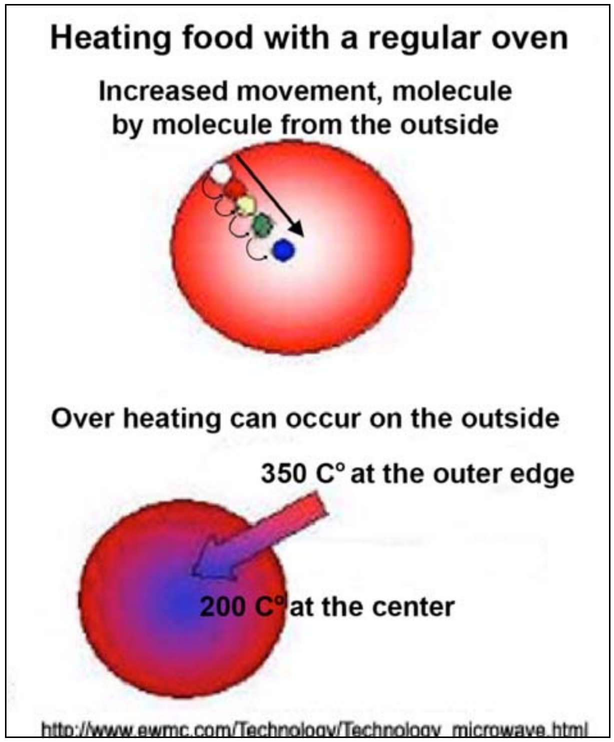
The second through fourth paragraphs focus on regular ovens, supported by the header before the second paragraph, “How do regular ovens heat foods?” The second and third paragraphs are structured as a process/sequence of how foods heat, “when you turn on a regular oven…” The fourth paragraph is also structured as a process/sequence, but the purpose of this paragraph is to describe why it takes time for a regular oven to thoroughly heat foods.

The fifth and sixth paragraphs then focus on microwave ovens, supported by the header, “How *microwave* ovens work,” placed before the fifth paragraph. The fifth paragraph provides a contrast with regular ovens when introducing how microwave ovens work. The sixth paragraph is then structured as process/sequence as it describes what happens, “When you turn on a microwave oven…”

The last paragraph of this text then entails a contrast structure as it describes how microwave ovens tend to heat/cook foods faster than regular ovens.

Structure and Function of Cooking with Ovens Graphic MW1: The first graphic in this text (MW1) has the title, “Heating food with a regular oven.” This graphic is an adapted image from a website governed by the Environmental Waste Center (2007). Figure 5.3 is the graphic shown the same size as used in the texts.

Figure 5.3. **MW1**



The most salient feature of the MW1 graphic is color. In fact, this graphic is the only one from both the *Cooking with Ovens* and Bitter Blocker texts that utilizes an array of colors. The feature of color in MW1 can be considered its own mode (beyond the prose and graphic). For example, Kress and van Leeuwen (2006) note that,

> It is true that there is a dominant discourse of colour in which colour is primarily related to affect, and Halliday and others (e.g., Poynton, 1985; Martin, 1992) see affect as an aspect of the interpersonal metafunction. But the communicative function of colour is not restricted to affect alone. We think that colour is used metafunctionally, and that it is therefore a mode in its own right. (p. 228-229)

MW1 is an example of how color can function beyond the interpersonal metafunction and affect (i.e., stimulation of interest). Color in this graphic communicates information as well, which I discuss below. However, due to the fact that, in this case, the color is found within MW1 only, and no where else in the text, I discuss the features and meanings of the colors in conjunction with MW1 and the other features of the graphic.

Other salient features in MW1 include two large circles, which are used to portray the phenomenon of food heating in a "regular" oven and the movement of molecules within that food. One large circle is set at the top half of the graphic, and another large circle is at the bottom half of the graphic. Captions also appear above each large circle, describing the movement of molecules when food is heated. Labels are also included, set next to and overlaying the bottom circle.

Less salient features include 5 smaller circles of equal size, yet of varied colors, overlaying the top large circle. Multiple black, thin arrows also overlay the top large circle, set beside the smaller circles. The circles are set in line with each other from the outer edge to the center, in a diagonal direction, similar to the line of a hand of a clock set at the 11 o'clock position.

No framing exists within the graphic, which promotes maximum connection among all elements within the graphic. In this respect I consider MW1 one graphic. Although there are multiple images in MW1, the lack of framing sets the images into a singe unit of information.

Also, due to the top-bottom layout of the large circles, no central element exists in this graphic. This layout also represents the opposite notion of a given-new structure. The "ideal" (the general information) is on the bottom when generally the "ideal" should be on top. Likewise, the "real" (the more detailed information) is at the top when generally "real" information is placed at the bottom. The top-bottom setup also occurs with captions and images together: captions are set at the top, followed by the top circle, then another caption, followed by the bottom circle.

MW1 entails a narrative structure with a few embedded conceptual elements. The graphic contains action processes; geometric symbolism; a possible transactional process; and color, all of which provide the narrative pattern. Elements that represent the action processes include the curved and straight arrows (vectors). For example, five arrows overlay the upper large circle. One long thin, black arrow appears to the right of the line of small circles, its end touching the edge of the large circle and its head pointing to the center. Four small, curved, U-shaped arrows are set to the left of line of small circles. Each of the four arrows has its end close to one of the small circles, and its head pointing to the next small circle closest to the center. For instance, the end of an arrow is near the white circle close to the edge of the large circle. This arrow curves around like a "U" and its head points to the next (red) small circle. The next arrow's end is near the red small circle (and near the previous arrow head). This arrow also curves in a U-shape and its head points to the yellow circle. The other two arrows are set in the same pattern, pointing from the yellow small circle to green one, and the green small circle to the blue one.

These curved arrows along with the large narrow arrow on the top circle also entail geometric symbolism by representing a transfer of kinetic energy. That is, the arrows represent how energy of movement is transferred from one small circle to the next closest to the center, to the next, and so on. Other geometric symbols include all of the large and small circles in the graphic. Due to the lack of labeling, these circles could symbolize a range of entities, including real-world entities. One must infer and synthesize, from other elements in the graphic (such as the captions) and from the prose, what each circle represents. The intention of the graphic is to represent molecules (the small circles), and the transfer of movement of these molecules (the arrows), with respect to their placement in some type of food (the large circles). This is an example of how a reader must take information from other sources within the graphic itself as well as within the prose to make coherent meaning about the graphic.

The narrative pattern of MW1 is also revealed through the gradients of color (i.e., change in color). Change in itself is a process and therefore a narrative representation. For example, the upper large circle is colored with a gradient of red to white. The outer edges of the upper circle are a bright red. From the outer edges to the center the red color turns lighter, and the center is white. This gradient may represent a change in some type of characteristic of which the "food" that the large circle represents. If one followed the ideal-real structure of caption-sign/symbol, in which each caption is associated with the symbol below it, then the red-to-white gradient would represent the amount of movement of molecules that make up the food.

The lower large circle is also colored in a gradient. Yet in this circle the color changes from red on the edges of the circle to blue in the center of the circle. Part of a thick, colored arrow (including its arrowhead) overlays the circle. The arrow lays in a diagonal direction, similar to the line of a hand of a clock set at the half past one position. The end of the arrow is set outside of the large circle, and its head is pointed towards the circle's center. This arrow is also colored in the same gradient as the circle. The end of the arrow is red and the color changes to blue at its head. Again, if one follows the ideal-real relationship, the color gradient can be translated as representing the level of heat in certain areas of the food. Kress and Van Leeuwen (2006) discuss the common use of colors to represent meanings, especially blue to represent cold and red to represent hot, "…the red end of the scale remains associated with warmth, energy, … and the blue end with cold, calm, … The cold-warm continuum has many correspondences and uses." (p. 235).

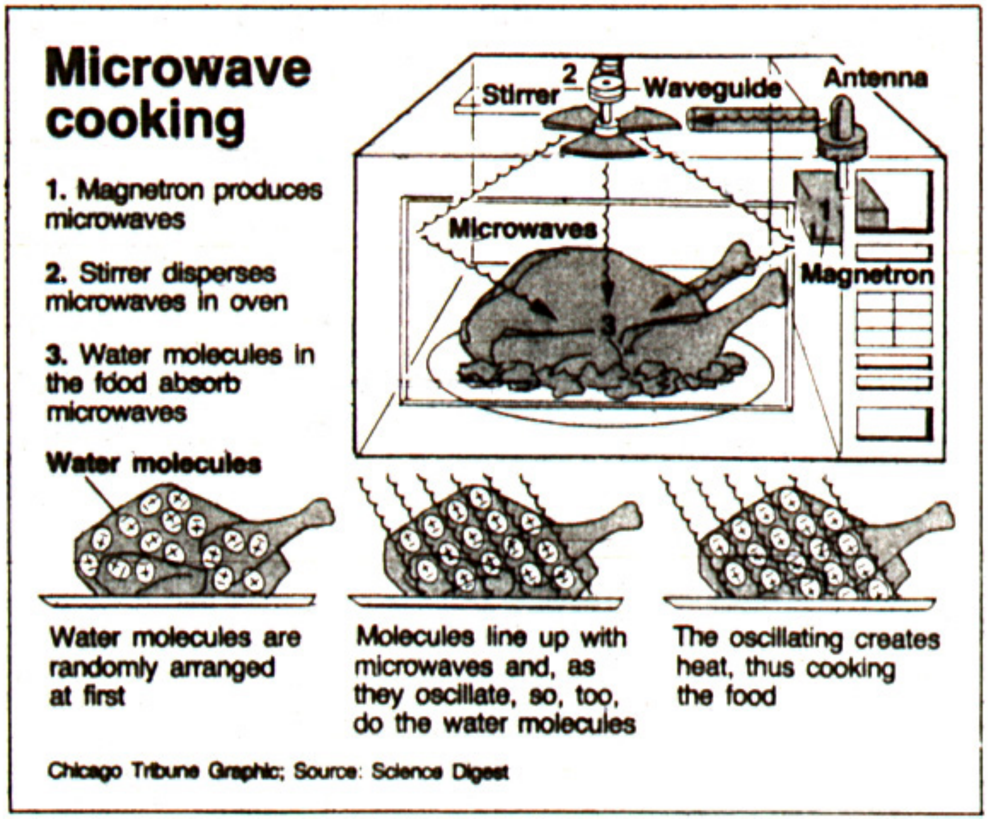
Various colors also make up the small circles (the molecules). A small white circle touches the edge of the large circle. Next to it is a small red circle. Beside the red circle lays a small yellow circle, then a small green circle. A small blue circle is set next to (but not touching) the green circle, and lies close to the center of the large circle. The meanings of these colors, however, do not seem to follow any common pattern. For example, the white little circle on the outskirts of the large circle is opposite of the large circle's white center. What the colors mean is up to the reader. If the reader has identified the circles as molecules, then based on the captions the colors may represent the amount of kinetic energy, or a different type or molecule. This lack of direction in interpretation of the color may increase the difficulty of students' meaning making and understanding of the graphic.

An area of confusion may also come into play when translating the arrows with respect to the 5 smaller circles. One might interpret the representations as a possible transactional process. The representations are not intended to represent a transactional process, yet the multiple colored circles, and curved arrows pointing from one to the other and so on, *could* present a conversion. By conversion, the circles do not just pass on what they receive (which is represented by the arrow), but actually transform that thing. In this case the transformation could be represented by the change in color. So a question might develop: does the set of colored circles and arrows represent the circles changing by receiving and passing on the element represented by the arrows, or, do the circles change the thing represented by the arrows? If we assume the arrows represent the transition of energy of movement, then we know that the energy of movement is not necessarily changed. Without the captions and information in the prose, this information would not be available and apparent.

Some elements of MW1 also support a conceptual pattern. As I touched upon earlier, color represents entities (e.g., different colors represent different types of molecules). The circles themselves are also symbolic elements in that the large circles represent food and the small circles represent molecules. The small circles set over the top large circle also provides a type of conceptual - analytic structure in which a part-whole conception is represented. The small circles are parts of the large circle. This interpretation matches the scientific idea of molecules making up food. However, the lack of labeling makes it difficult for a reader to make such a connection and may promote confusion. It may also direct the reader to assume the symbol represents something that is communicated in the prose and/or captions. This feature can be either hinder or help a student's comprehension of the text, depending if the interpretation is structurally and scientifically correct.

Structure and Function of Cooking with Ovens Graphic MW2: The second graphic in this text (MW2) is of a turkey in a microwave oven, and three smaller turkeys lined next to each other from left-to-right, set below the microwave oven image. This graphic, titled, "Microwave cooking," was taken from a newspaper science question-answer section that explained the effects of microwaves on food (New York Times News Service, 1985). Figure 5.4 is the graphic shown the same size as used in the texts.

Figure 5.4. **MW2**



Notice that, unlike the previous graphic, MW2 has no color. Instead the most salient feature in this graphic is an image of a turkey in a microwave oven. This image is set at the top right-hand section of MW2. The title of this graphic, "Microwave cooking," is in bold black print at the top left corner and is also a salient feature. Other salient features include three smaller turkeys at the lower portion of MW2. These turkeys are set horizontally in line with each other; one at the left of the graphic, one in the center, and one to the right. Less salient features of MW2 entail specific parts of the microwave that are labeled with words and numbers, wavy lines and arrows, and white ellipses set within the three smaller turkeys. One of the characteristics that make all of these features salient is shading. Each of the turkeys and specific parts of the microwave oven are outlined in black and shaded in gray. This shading provides emphasis on the specific features. The shading of the bottom small turkeys also provides contrast with the white ellipses that overlay the turkeys, making these symbols also stand out.

I consider this graphic complex because there is no central element to the graphic. The turkey in the microwave oven is the larger and more salient feature of MW2. Yet it is set just above and slightly to the right of the graphic's origin. The saliency of the turkey also comes into play when identifying the space the entire microwave oven image occupies. The image takes more than one half the space of the entire graphic both horizontally and vertically. The lines that make up the microwave oven are the only type framing in MW2. Framing of the elements inside the microwave may be a secondary role of the lines, besides the conceptual role of making up the microwave oven. No other framing is applied within the graphic. Similar to MW1, the lack of framing within MW2 provides maximum connection between the elements of the graphic.

Although not as obvious as other graphics, MW2 does present a left-right, given-new structure. The bottom turkey to the left represents a turkey and its molecules as it is (i.e., as "given") and the center, and then right turkeys represent the molecules and microwaves as what happens in a "new" situation (i.e., "new" information). MW2 also presents a top-bottom, real-ideal pattern. The top image of the turkey in the oven is a more general depiction of microwave cooking, whereas the bottom three turkeys provide a more detailed depiction of what happens when microwaves are used on food.

This graphic is also complex in that it depicts both narrative patterns and conceptual patterns. It is difficult to discern if one pattern is minor, and therefore embedded within the major pattern. Usually one can identify the major pattern by the elements of those patterns. As noted by Kress and Van Leeuwen, "Which of these structures are major and which are minor is, in visuals, determined by the relative size and conspicuousness of the elements" (Kress & Van Leeuwen, 2006, p. 107). In this case the elements that make up the conceptual and narrative patterns are relatively the same in terms of size and saliency. MW2 includes narrative elements such as action processes, geometric symbolism, and circumstances. The conceptual elements in this graphic include classificatory process and analytical processes, including inclusive analytical structures and topographical elements. Further description of the narrative and conceptual elements follow:

The wavy lines and wavy arrows take on an action process as well as geometric symbolism. The squiggle of the lines and arrows symbolize the entity of a microwave.

They also represent the action of movement among the microwaves. For example, these symbols are presented within the microwave oven image, and are also set over the middle and right bottom turkeys. The wavy lines and arrows in the microwave oven image are placed in a specific arrangement, such that one could interpret two of the vectors as "beginning" near the fan-like image labeled as the stirrer, pointing and "reflecting" off the walls of the oven, and going towards the turkey. A third vector begins at the stirrer and points directly towards the turkey. The wavy lines on the middle and right bottom turkeys are set such that they exceed the bounds of the tops of each turkey, and are lined up parallel to each other in a diagonal fashion in line with ellipses that also overlay the turkeys. Due to the similarity of the lines with those in the microwave oven, one can interpret them as microwaves that are moving through the turkeys.

Other elements that provide a narrative pattern in MW2 are the circumstances. Recall that circumstances are secondary signs and symbols that, if left out, would not affect the major information that the narrative pattern tells. Lack of circumstances would, however, result in loss of information. For example, the lines set under the turkeys in this graphic are "plates" with which the turkeys are set. These plates provide more context. That is, it provides more of a story than just the turkey would show. The contextualization may also allow the reader to better identify the turkeys as such, for a common image of a cooked turkey includes it sitting on a plate.

Another circumstance in this graphic is the small plus and minus symbols set within the white ellipses (the "water molecules") in the bottom small turkeys. In fact, one vague difference between the middle and right turkey is how the ellipses are arranged with respect to the plus and minus signs. The ellipses are aligned the same way, but the placement of the plus and minus signs in the ellipses of the middle turkey are opposite from those of the right turkey. In the middle turkey, the plus signs are above the minus signs in each ellipse. In the right turkey the plus signs are below the minus signs. A person who is knowledgeable of the concept of polarity of molecules might attend to, maybe even look for, the plus and minus signs. They are important features in depicting how microwaves interact with molecules. In fact, the change in placement of these signs with the ellipses provides more of the story depicted in the graphic. However, not only are the signs dulled, but they are also disconnected with the rest of the information portrayed in the graphic and could create confusion or uncertainty if a reader attends to them.

These signs, and the ellipses they occupy, also provide a conceptual pattern. Similar to how the small circles in MW1 are part of the whole of the large circles, the signs and ellipses in MW2 also make up conceptual - analytical structures (the "part-whole") in MW2.   Also similar to MW1, the ellipses can be interpreted as molecules that make up the turkeys (the food). This time the ellipses are labeled as molecules.

Other features in MW2 provide similar types of analytical structures. For example, the lines that make up the buttons and windows of the microwave oven, and the specific shaded features, together depict the "parts" of the oven. The placement of the signs and symbols that make up the microwave oven are also important in providing a conceptual pattern because they accurately represent the "physical spatial relations and the relative location" of the elements that make up the thing they collectively depict. In this case the signs and symbols are placed such that they represent parts of an oven that matches the kind of microwave oven with which a reader can relate. (Kress & Van Leeuwen (2006) would call this set of signs and symbols *topographical elements*.)

Instructional Description of the Prose and Graphics – *Cooking with Ovens*

Instructional Ideas of Cooking with Ovens Prose: Analysis of the prose reveals two major instructional ideas throughout this text. The first is that two different ovens heat/cook foods in different ways. The statement, "ovens heat foods" is one that students most likely know by experience and by the common use of the word "oven" to mean the tool we use to heat/cook foods. (The implicit notion that other tools can heat/cook foods, such as a stove, is not apparent, as the focus of the text is about ovens and two different types of them). However the instructional component is identification that the *ways* two types of ovens heat foods is different, and describing these *ways* (the processes) each undergoes to show the difference. This idea is further supported by the compare/contrast structure of the text. Related phrases in the text include the statements, "Regular ovens use hot air to heat food," as well as, "Microwave ovens are different because they do not use hot air to heat food," and, "Instead, they [microwave ovens] work by heating food with…microwaves."

The second instructional idea is that as things (such as air and foods) heat, the molecules (that make up the thing) move faster. This idea is the means to instruct the reader how two ovens heat/cook foods differently. In a sense, it is an embedded instructional idea, a theme presented a total of six times throughout the text. This second theme is consistent to the learning goals of the *Smell* unit. In fact, the text was written to be read when students learn about the movement of molecules when solids heat.

Another instructional idea involves the time it takes to heat/cook foods. This idea is less central in the text than the previous two instructional ideas. Those readers who have used both microwave and regular ovens may already know that, "Microwave ovens tend to heat food faster than regular ovens," (as stated in the last paragraph of the text). However, the text uses this idea to further emphasize the contrast between the ways the two ovens make food molecules move faster. The concept of *time* to heat foods is first introduced in the fourth paragraph. This paragraph explains *why* it takes time for regular ovens to thoroughly heat/cook foods. Then, the contrast between the two ovens is explained in the last paragraph of the text. This occurs by reiterating information already stated in the text. For example, paragraph four contains the following statements: "…*all of the* food *molecules* don't *move faster at once*."; and, "… because the food molecules are colliding *one by one*, from *the edges of the food to its center*." Similar phrases again occur in the last paragraph: "…microwaves can make *all of the water molecules in the food* move faster, *all at once*."; and "…each food molecule to move faster *one by one, from the outside in*, like regular ovens."

The prose also includes details that instruct the reader about science ideas. These details indirectly support the overall topic of how ovens heat foods and the movement of molecules in food as the food heats. Two such examples are (1) characteristics of microwaves: that microwaves are, "a form of light that we cannot see" and as a form of light they bounce and are absorbed; and (2) the actual speed of molecules, that, "they move back and forth about a million times a second!"

Instructional Ideas of Cooking With Ovens Graphic MW1: The header of this graphic communicates two general instructional ideas - that of (1) heating food and (2) the heating of food by use of a regular, conventional, oven. Without the header, the aspect of how regular ovens work, and how they heat food, could not be realized. Heating food is the more salient of the general instructional ideas represented in the graphic. Other, more specific, instructional ideas are also shown in the graphic. They include the movement of molecules increasing (as food heats); movement being transferred to each molecule (as food heats); the increase and transfer of movement goes from outside to inside; and when something is heated there becomes a gradient of hot on outside to cold on inside (heating foods can result in outside parts to be hotter than inside parts). I placed parentheses around the phrases involving food heating because the aspect of "heating food" is only communicated by the graphic's header. Only if the reader is able to synthesize and integrate the instructional ideas from the top and bottom images and labels, another possible instructional idea becomes apparent. That is, the gradient of hot-to-cold from outside-to-inside directly relates to the increased movement of molecules from outside-to-inside. Together, these specific instructional ideas support the instructional theme that as things heat, the molecules (that make up the thing) move faster. As I stated earlier, this instructional idea is consistent to the learning goals of the *Smell* unit and consistent with one of the goals of the text.

Instructional Ideas of Cooking with Ovens Graphic MW2: The cumulative instructional idea of this graphic involves how microwave ovens work to heat food. It follows one of the instructional themes of the prose and MW1: that microwave ovens heat and/or cook food in a specific way. The ideas of how microwave ovens work are presented as stepwise details of the process. These instructional details include: certain devices in the microwave perform to make and distribute microwaves; microwaves move around the microwave oven in straight lines (and eventually travel) to the food in the oven; when microwaves "hit" food, different things happen – (randomly arranged) molecules absorb microwaves; the molecules "line up" based on the polarity; the oscillating effect of microwaves make molecules also oscillate; the food heats as the molecules oscillate.

<u>Description of the Prose and Graphics' Interestingness – *Cooking with Ovens*</u>

Potentially Interesting Components of Cooking with Ovens Prose: As I stated earlier, I used criteria backed by theories and descriptions of student interest to identify phrases and propositional clusters in the *Cooking with Ovens* prose that may be interesting to a reader. Table 5.1 identifies the words or phrases that may be interesting to the students and why.

Table 5.1 - Potentially Interesting Components of Cooking with Ovens Prose

Words/phrases	**Paragraph #**	**Why may be interesting**
Pizza; hot chocolate as foods to heat	1; 4; 7	Possible relation to students' experiences
"see coils in the oven get red hot"	2	Possible relation to students' experiences
"hot air in the oven"	3	Possible relation to students' experiences
"…when you take pizza out of the oven too early, the inside of the pizza is still cold"	5	Possible relation to students' experiences
"microwaves"	5	Disequilibrium – confusion of what is meant by microwaves
"they [molecules] move back and forth about a *million times a second*!"	6	Surprise & Disequilibrium - beyond prior knowledge; use of exclamation point Gives context to normally abstract idea

As the table shows, most of the statements that I identified as possibly interesting in the *Cooking with Ovens* text may relate to students' experiences. In these cases, the words or phrases may be interesting because the students have likely experienced the communicated idea, and may be able to relate to the prose. For example, students may be interested in pizza. Also, "Microwave" is the only scientific and technical word that might stimulate interest. In my pilot study, I noticed that some students did not distinguish use of the word "microwave" from the entity of a microwave oven. Therefore reading about microwaves and microwave ovens may stimulate confusion over the use of the term, and therefore fall into the category of disequilibrium.

Another feature of the prose that may be potentially interesting is the use of exclamation points. In the *Cooking with Ovens* prose, the exclamation point is used only once. The exclamation point was used to emphasize the high speed of the molecules, and provide a "wow" factor with the idea. The exclamation point itself may stimulate attention to, and interest in, the sentence it supports. However, interest might also increase because of the novelty of exclamation points when reading scientific texts.

Potentially Interesting Components of Cooking with Ovens Graphic MW1: When discussing the structural and functional features of MW1 I discussed the ambiguity of what the circles in the graphic represent. This ambiguity also makes MW1 a non-personal graphic. For example, the MW1 does not portray any identifiable real-world object. There also exists no degree of realism, and instead incorporates the abstract signs and symbols to represent entities in the world. All of these factors support the objectivity of the graphic, in which little interaction among the reader and graphic exists. The graphic "offers" information yet does not take the reader into consideration. This type of interaction can evoke a sense of disengagement for the reader.

Even though the graphic is non-personal, some features may evoke and/or support student's interest in the graphic (Table 5.2). One such feature is color. As I discussed earlier in the structure and function section of the graphics, color commonly promotes interest. The color of MW1 is also enhanced due to the non-color, black and white, that spans the rest of the *Cooking with Ovens* text. The color may even provide a "wow" factor, not in the information it represents, but in the difference between the multiple colors of MW1 and the non-color of the rest of the text.

Table 5.2. Potentially Interesting Components of Graphics MW1 & MW2

Potentially interesting components	**Graphic**	**Why may be interesting**
Color	MW1	Variety / Novelty
Circles (resemble pizza, earth, bubbles)	MW1	Similarity of signs/symbols to real-world or experienced objects
Turkeys and circumstances around turkey (e.g., plate and garnish)	MW2	Possible relation to students' experiences
Microwave oven features	MW2	Possible relation to students' experiences
Similarity of "stirrer" with that of a fan	MW2	Possible relation to students' experiences

Other features of MW1 that may be interesting depend upon the signs and symbols in relation to the experiences of each individual. If a reader identifies an indirect relation between the signs and/or symbols and something he or she experienced, then interest may be activated and possibly sustained. One example of this type of possible interest is the circular shapes of the represented food in MW1, and their similarity to pizza – an experienced type of circular, red food that is also discussed in the prose.

Another example of a possible relation is again the circular, red and blue representation and the circular shape of pictures of the earth.[17]

Potentially Interesting Components of Cooking with Ovens Graphic MW2: MW2 is similar to MW1 in that it entails an objective perspective. Yet unlike MW1, this graphic is a compromise between naturalistic and technological orientations. The naturalistic orientation is made by elements that provide some interaction between the graphic and the reader. Details, such as the buttons and window of the microwave oven, the plates and other stuff on the plate, provide background and context (Table 5.2). And, signs and symbols together provide representation of what the things are in nature (e.g., shape and view of the turkeys and the microwave oven). These represented objects may invoke interest, especially if an individual has positive attitudes toward the objects. Again, the interest is based on the individual's own experiences. MW2 also incorporates technical information; symbols that are abstracted beyond that of nature (e.g., the molecules) and therefore difficult for a reader to interact. Similar to MW1, the signs and symbols that are not directly related to an object in nature, or those that are abstracted beyond one's experiences, may invoke a sense of disengagement.

Informational Relationships between the Prose and Graphics – *Cooking with Ovens*

Tables 5.3 and 5.4 identify the relationship of information provided by the prose and each graphic with respect to each other. I used ideas highlighted by analysis of the structural, potential interest, and instructional ideas in the text, and identified whether the prose and graphics were incompatible or complementary in representing the ideas. Table 5.3 outlines incompatible information from each representation, including the ideas as new, missing or inconsistent. Table 5.4 outlines redundant and/or complementary information.

[17] The examples about interest in this paragraph are drawn from idiosyncratic statements by the students in the study.

Table 5.3. Incompatible Relationships of Prose and Graphics MW1 & MW2

Summary Information by Relationship	**How Represented & Comments**
Information in Prose Missing in Graphics MW1 and/or MW2	
Movement Molecules & Food Heating Connection	[Prose Paragraphs 2 and 3 : MW1 & MW2] – explicit connection lacking. [Connection between warm food and faster molecules only occurs in MW1 if reader connects top and bottom images]
Varied Cooking Times	[Paragraphs 4 and 7 : MW1 & MW2] – the time it takes to cook/heat foods depicted neither graphic.
Outside-to-Inside (3-D Explanation)	[Paragraph 4 : MW1&MW2] – none in MW2; MW1 depicts 2-D representation and possible interpretation of “surface” of food being hotter/colder.
All Molecules	[Paragraph 7 : MW2] – a images show multiple molecules not “all” molecules
Center and Outside Heating at Same Time	[Paragraph 7 : MW2] – MW2 lacks depiction of temperature
Hot Air in Oven	[Paragraph 3 : MW1] – air not represented
Speed of Molecules	[Paragraph 6 : MW1 & MW2] – “they [molecules] move back and forth about a *million times a second*!” [graphics are static]
Exclamation point (phrase above)	No representation to show exclamation
New and/or Additional Information in Graphic	
Parts of Microwave Oven	[MW2] – shows and describes various parts.
Polarity in Molecules; Alignment Molecules	[MW2] – depicts polarity as plus and minus signs in molecules; shows role of polarity in heating foods with microwaves (e.g., alignment molecules).
Movement of Light	[MW2] – microwaves moving in straight lines.
Inconsistent/Contrasting Information between Prose and Graphic	
“Regular Oven”	[Paragraph 1 and Heading 2 : MW1] – No complete relationship: no image of a regular oven in MW1.
Molecular Movement in Air and Food	[Paragraph 3 : MW1] – MW1: big red circle could depict air or food
Cold / Hot Focus	[Paragraph 4 : MW1] – Prose: Inside of food (“pizza”) is *cold*.; MW1: *overheating* on outside of food
Eyes Cannot Detect Microwaves	[Paragraph 5 : MW2] – MW2 depicts microwaves; no information is depicted to show what microwaves are.

Table 5.4: Complementary Relationships of Prose and Graphics MW1 & MW2

Summary Information by Relationship[a]	**How Represented and Comments**
Elaboration of Information in Prose	
*Temperature Food	[Paragraph 4 : MW1] – pizza as “cold”; MW1: specific temperature differences
Magnetron	[Paragraph 5 : MW2] – “a device…makes…”; MW2: “magnetron makes microwaves” (from caption) and depiction of magnetron
Microwaves Moving	[Paragraph 6 : MW2] – “The microwaves… move in the oven in all directions.”; MW2: “stirrer disperses microwaves” (from caption) and depiction of microwaves moving in different directions away from stirrer.
*Movement Molecules	[Paragraph 6 : MW2] – “The microwaves make the water molecules move back and forth faster.”; MW2: “oscillate”
Similar / Redundant	
“Regular” Ovens and “Microwave” Ovens	[Headings and Graphic Headers] – prose matches with the respective graphic labels
*Molecule Movement	[Paragraphs 1, 3 & 4 : MW1] – MW1 top caption and image for “increased movement”
Collision	[Paragraphs 3 & 4: MW1] – MW1 top image can be interpreted as each molecule “colliding” into the next molecule. [note: neither representation details the collision as elastic]
*Molecule Movement & Food Heating	[Paragraphs 3 & 4: MW1] – Connection between warm food and faster molecules *only occurs* in MW1 if reader connects top and bottom images
*Faster Moving Molecules Begin at Edges; Outside to Inside Process	[Paragraphs 4 & 7: MW1] – MW1 top image depicts transfer of movement from edges of food to its center; shows a one-by-one system; both top and bottom images show arrows going from “edge” to it center. Caption uses similar phrase (“molecule by molecule”)
*Process of Microwaves in Oven	[Paragraph 6 : MW2] – MW2 images depict parts of the process described in prose; captions also indicate the process.
Microwaves Absorbed	[Paragraph 6 : MW2] – MW2 caption tells of water molecules absorbing microwaves
Pizza ; Cold Pizza [when take out of oven too early]	[Paragraphs 1,4,5 & 7 : MW1] – Pizza; hot chocolate as examples of food; MW1 large circles have red color; similar to shape and color of pizza; bottom image depicts a colder center in the represented food.
See Coils get Red Hot	[Paragraph 2 : MW1] – MW1 red representing hot
Microwaves	[Paragraphs 1,5 & 7 : MW2] – MW2 labels & representation (wavy lines)

a: * = maps to instructional concepts central to the text

Structurally the prose presents information as compare/contrast. The global text structure (Figure 5.2) also shows that the graphics can be regarded as compare/contrast in that MW1 relates to the regular oven and MW2 relates to the microwave oven. However, as one can discern when comparing the graphics, the information represented does not match a compare/contrast structure. In a sense, the top portion of MW1 is similar, but not as detailed as, the information provided by the lower three turkeys in MW2 – that is, how molecules move if a food was heated with a regular oven versus a microwave oven.

Most incompatible ideas are instructional ideas, yet the fact that they are incompatible is mostly due to the inability of graphics as depicting both information that is concrete to students' experiences (e.g., a turkey and microwave) and information that our eyes cannot detect (e.g., molecules and light). For example, the prose mentions "all molecules" and discusses food and air molecules. Yet the graphics fail to depict air molecules, and cannot depict all molecules of a substance. Similarly, the graphic depicts microwaves and the movement of microwaves in a microwave oven, yet the depiction is simplified and contrasts with the idea that eyes cannot detect them.

The other idea incompatible across the representations is the explicit connection of food heating as molecules that make up the food moving faster. Recall this instructional idea is a learning goal for the *Smell* unit. A reader may (hopefully) make the connection with MW1 when interpreting the images together. Yet, as noted earlier, the connection is not explicit. Also, MW2 does not depict the connection.

Complementary relationships, however, do include the increased movement of molecules as part of the process each oven undergoes to heat foods. Also how each oven makes molecules move faster is demonstrated in each graphic and complementary with the description in the prose.

DESCRIPTION OF THE BITTER BLOCKERS TEXT

This text was written with the goal of showing students how knowledge of the particulate nature of matter applies to other contexts besides explaining how odors travel. The original version of this text was a newspaper article from the New York Times (Day, 2003). This final version, however, is constructed expository text that contains the same content as the original article, yet was adapted using the reader design principles. The text introduces substances, called bitter blockers, which reduce the amount of bitter one tastes when eating or drinking bitter foods. The bitter blockers act different than salt and sugar – the common ingredients used to make foods taste less bitter. The text also explains how bitter blockers work, and what scientists have found about the substances.

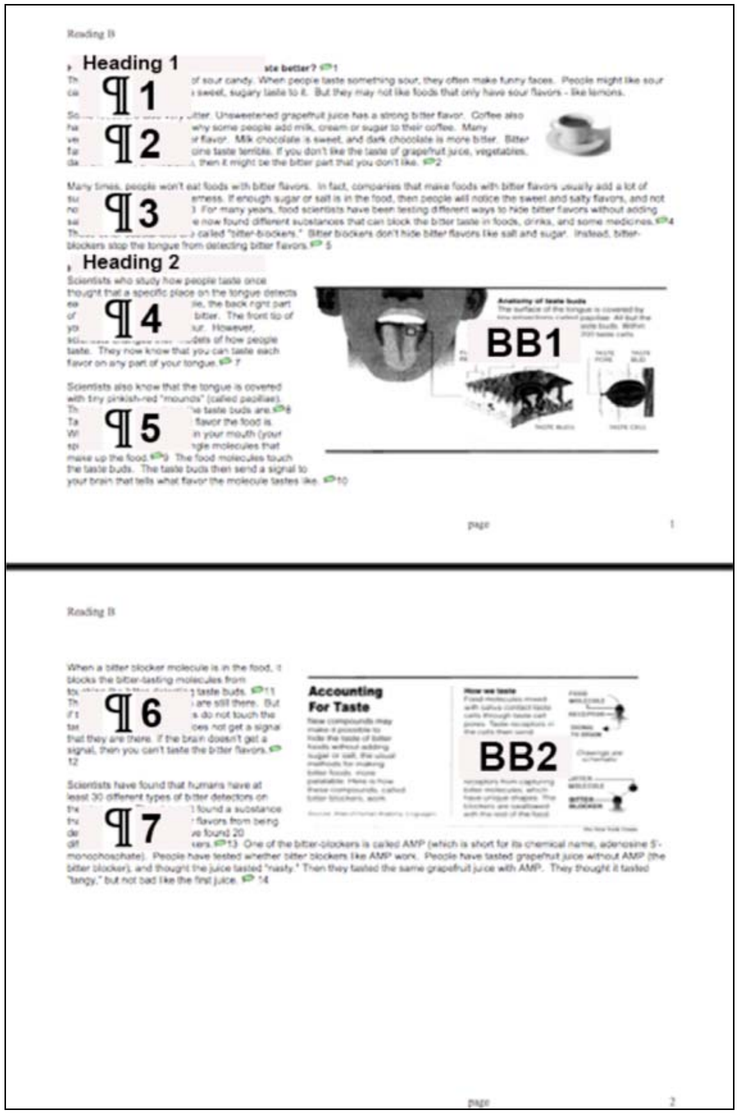
Visual Description of the *Bitter Blockers* Text

Like the *Cooking with Ovens* text, this one also occupies two pages, yet the pages are set in landscape mode with the first page above the second page. Similar to the *Cooking with Ovens* text, within the entire text the lines of each paragraph are single-spaced, and each paragraph is separated by an empty space. Figure 5.5 shows a visual of the text.

On the first page the reader would see five paragraphs, one small graphic (a picture of a cup of coffee) and a large graphic containing multiple illustrations. A bolded header introduces the text, followed by three paragraphs. A second bolded header is set after the third paragraph, and precedes paragraphs four and five. The first and third paragraphs take the width of the page. The second paragraph takes about three-fourths of the page's width. A picture of a mug filled with dark liquid occupies the right quarter of the page and is aligned to be the same length as paragraph two. Heading one and these three paragraphs also occupy half of the length of this first page.

The fourth and fifth paragraphs occupy about one-third of the left side of the page. These two paragraphs, in addition to heading two, also occupy about half the length of the page. A graphic (BB1), outlined by a top and bottom line, takes the bottom right space of page one. It is aligned to the right of, and takes about the same space lengthwise as, paragraphs four and five. The width of BB1 is about two-thirds the width of the page. This graphic is also presented in shades of black and gray, and the prose is black print.

Figure 5.5. **Visual Layout of Bitter Blocker Text**

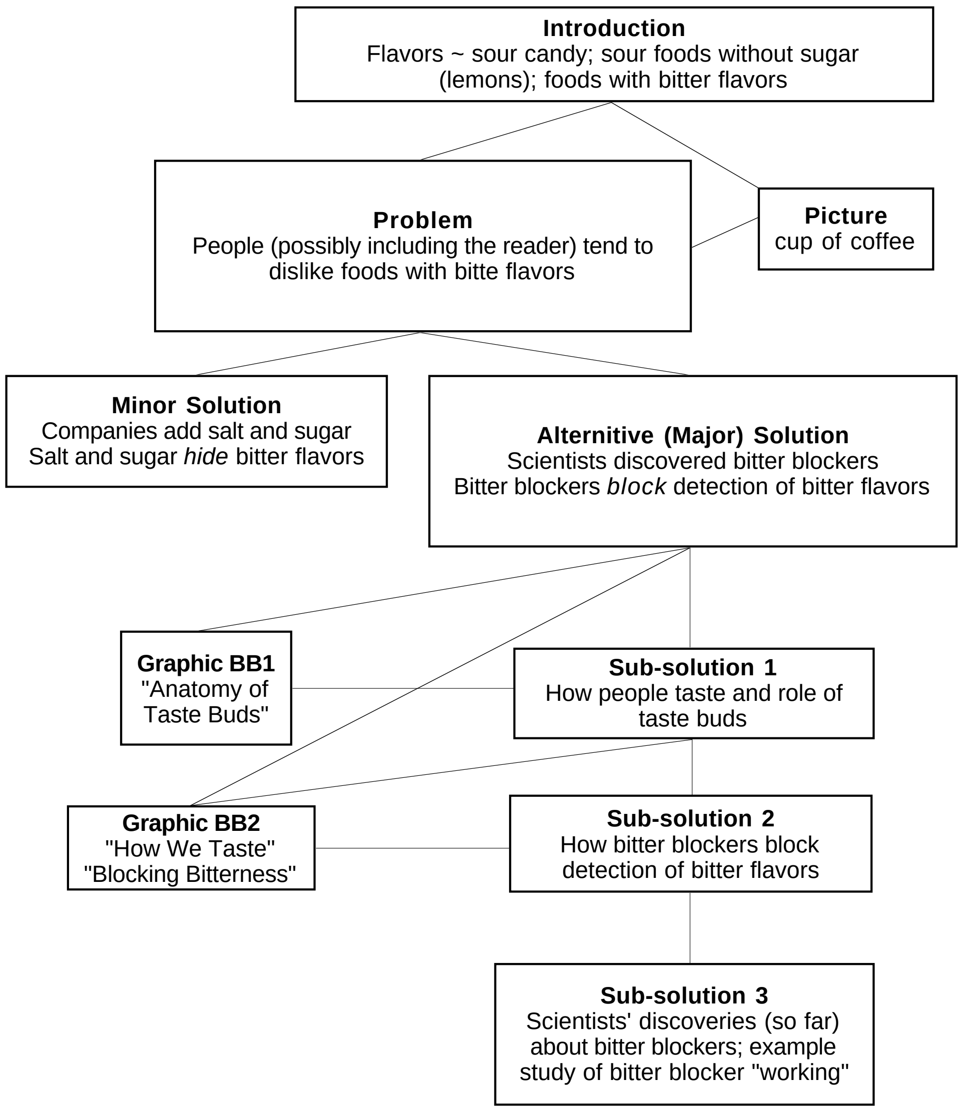


On the second page the reader would see two paragraphs (six and seven) that fill about half the length of the page. The bottom half of the page is white space. Another graphic (BB2) is set to the right of the sixth paragraph. The seventh paragraph wraps around BB2 such that the first half of paragraph seven lies to the left of the graphic, and the second half lies below it. Both the graphic and the print on this page of the text are black.

Structural Description of the Prose and Graphics – *Bitter Blockers*

The global text structure of the *Bitter Blockers* text is problem/solution. Figure 5.6 represents this global structure (Donovan & Smolkin, 2002).

***Figure 5.6.* Global Structure & Visual Diagram of Content Relationships: *Bitter Blockers* Text**



The prose initiates a problem regarding people's dislike of bitterness in foods. It then poses two solutions: The first solution is minor to the text – that is, to hide the bitter flavors with excess salt and sugar. The second solution is major to the text – that is, scientists have found a set of substances, called bitter blockers, that work to reduce the amount of bitter one might taste when eating/drinking foods. The text (prose and graphics) then provides information about this major solution.

Structural Description of Bitter Blocker Prose: The problem (and an indication that there is a solution) is introduced by the text's header, "How can molecules make bitter foods taste better?" The problem is further introduced in the first two paragraphs by leading the reader from the topic of eating sour candy and foods (and possibly disliking the sour taste) to eating (and disliking) foods with strong bitter flavors. In fact, the first two paragraphs were written as a means to stimulate students' thinking about, and interest in, the problem of not enjoying bitter foods.

After the first two paragraphs, the prose becomes more complex in that it has a minor, implicit solution that arises before the major solution: that people and companies can circumvent the problem by adding large amounts of salt and sugar to foods. The addition of salt and sugar is mentioned twice in the texts, in the second and third paragraphs. The statement in the second paragraph is an implicit solution whereas in the third paragraph the statement is an explicit solution.

> [In paragraph 2 – implicit notion]: Coffee also has a bitter flavor, which is why some people add milk, cream or sugar to their coffee.
>
> [In paragraph 3 – explicit notion]: Many times *people won't eat foods with bitter flavors*. In fact, companies that make foods with bitter flavors usually add a lot of sugar or salt *to hide the bitterness*. (italics show the explicit notion).

I call this solution minor due to its implicitness, its lack of saliency, and the fact that the major solution is an alternative to adding salt and sugar to foods. I use "minor" in a sense that this solution is minor to the overall prose.

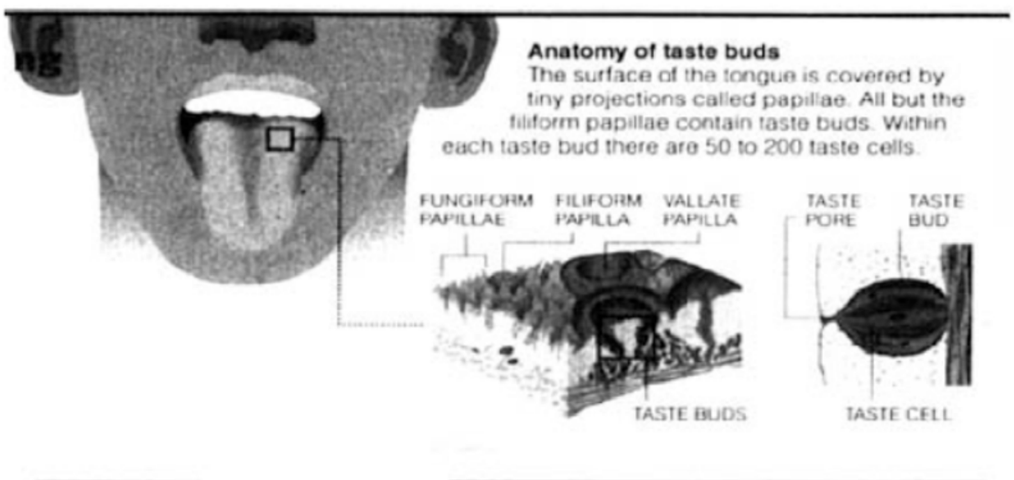
The second and third paragraphs include both explicit and implicit features of the problem and solution and are structured in the following pattern: The major problem (most people do not like / will not eat foods with bitter flavors) precedes a minor solution (people/companies add a lot of salt and sugar). Then scientists' goal of finding an alternative solution is introduced, followed by the major solution (bitter blockers).

A header, "How do bitter blockers work?" lies above the fourth paragraph, signaling the focus of bitter blockers for the following paragraphs. The fourth paragraph begins a description of how people taste. The fifth and sixth paragraphs contain an embedded process/sequence structure to describe how people taste (paragraph five) and how bitter blockers limit the amount of bitter a person tastes (paragraph six).

The seventh, and last, paragraph returns to a description structure, as it returns to the notion of scientists discovering the bitter blockers and news about the study of bitter blockers.

Structural and Functional Description of Bitter Blocker Graphic BB1: The signs and symbols of the first graphic in this text (BB1) make up three major images and captions. The left-most image is what I call the "person with the tongue" image; I call the middle image a "zoom-in with layers"; the right most image is called the "zoom-in of a taste bud". This graphic, titled "Anatomy of Taste Buds," was the first part of an image taken from a newspaper article about bitter blockers (Day, 2003). Figure 5.7 is the graphic shown the same size as used in the text students read.

Figure 5.7. **BB1**



Of the signs and symbols in this graphic, the size, shading and contrast of white teeth with dark shaded facial features make the person with the tongue the most salient feature in this graphic. The saliency of this image also comes into play when identifying the space it occupies. The image is located and takes up the entire space of the graphic's upper left quadrant, though the tip of the tongue touches the vertical center, and the chin is located in the lower left quadrant. The image therefore takes up more than half the space of the entire graphic vertically.

BB1 also lacks a central image, which makes the person with the tongue image most salient. In fact, most of the prose of the caption is in the upper right quadrant (but only takes about half of the space). And, most of the middle (zoom-in with layers) image lies in the lower right quadrant, along with the right (zoom-in taste bud) image. Only the labels of these images extend beyond the quadrant and lie in the upper right quadrant. This also makes the upper right quadrant entirely composed of words.

No framing is applied within the graphic. The lack of framing provides maximum connection between the elements of the graphic. This connection is enhanced with lines, sets of which connect the "tongue" with the middle (zoom-in with layers) image and connect the image to the right (zoom-in taste bud) image. I discuss the role of these lines below.

The information in BB1 is presented as left-right, given-new with respect to the images. The left-most element of a person sticking out his/her tongue is depicted as "given" in a sense that the representation shows how any person would look in the situation. The middle image represents the "new" information with respect to the tongue, and the right image provides new information with respect to the middle image. Captions in BB1 also lie to the right of the person with the tongue image, again providing a left-right view between the tongue and caption and presenting a sort of given-new pattern. In this case the captions present "new" information about the surface of the tongue.

BB1 also presents a top-bottom, real-ideal pattern. Again, the top-bottom can be viewed as the left person with tongue image as the top "general" information, and the other images as the "real", more specific, information.

Unlike the *Cooking with Ovens* graphics and BB2, BB1 entails an entirely conceptual structure. The graphic contains analytical, symbolic, and topological processes, all of which provide the conceptual pattern. Recall that analytical processes are the signs and symbols that make a "part-whole" representation. There are many different ways a part-whole structure is realized. In BB1, the shading, signs and symbols within each image provide a part-whole, analytical process. The lines that connect an image to the captions (i.e., the labels) also show an analytical process. Also, one type of analytic structure unique to BB1 is the sets of lines that form squares, one on the tongue and one on the middle (zoom-in with layers) image. The square that is set on the tongue connects with lines that lead the reader from the tongue to the middle (zoom-in with layers) image. Together these representations make an analytical process, showing the reader that the middle image is a "part of" the tongue (the "whole"), and magnified so that one could discern what makes up the surface of the tongue.

Another square lies on the middle image, and lines connect this square to the label "taste buds." Note that this square is difficult to detect due to the many features and dark shades that make up the middle image. Also, the label "taste buds" on right and middle images should lead a reader to identify the right-image is another magnification, this time of the taste buds represented in the middle image.

The magnification represented by the square and lines also takes on a symbolic role, which again supports the conceptual structure. Specifically, the square symbolizes a focus toward the part of the image it is set. In a sense it is telling the reader, "if you focus on this piece, [and magnify it], you would see…" Squares set as such do not always mean the object of focus is magnified. It is the role of the connected signs and/or symbols in conjunction with the role of the signs and symbols that make up the middle, (zoom-in with layers) image. The role of the signs and symbols in the middle image together provide a topological process. A topographical process occurs when signs and symbols that together represent an object do so by "accurately representing" the relations between the parts of the object in its natural setting, "but not the actual physical size" and/or distances of the object's parts or the object itself. Due to this topological role the middle and right images also have a higher naturalistic modality in that they represent, "the physical spatial relations and the relative location," of the object they collectively make (Kress & Van Leeuwen, 2006 p.98). These images are higher in naturalistic modality than the face with the tongue image, which looks like a cartoon drawing.

The features that communicate magnification and identification of the "parts" of a tongue take on three different roles that make up the graphic's conceptual structure (analytical, symbolic, and topological processes). However, due to the brightness and lack of color distinctions, the middle and right images are not clear and are difficult to make sense. What a reader might extract from this graphic, especially the middle and right images, is questionable due to the lack of clarity of these images.

Structural and Functional Description of Bitter Blocker Graphic BB2: This graphic includes three bold-faced headings. "Accounting for Taste" is in the largest font, found in the upper left hand corner. Two other headings, "How we taste," and "Blocking bitterness" have the same font size as the captions. This graphic was the second part of an image in the newspaper article about bitter blockers (Day, 2003). Figure 5.8 is the graphic shown the same size as used in the text students read.

Figure 5.8. **BB2**

As with the other graphics in this study, BB2 has no central element. Yet unlike the other three graphics, a salient feature of this graphic is the two columns of prose. The prose takes up about the left three-quarters of the graphic, whereas the images take up about the right one quarter. The entire left half of BB2 is prose and white space. The right half of the graphic about evenly split with prose (the left side) and then images (other signs and symbols on the right side). The way the prose and images are set makes the images as a minor feature in the entire graphic. The darkened words with larger font size also make the prose more salient in this graphic. Less salient features of BB2 include the small dark circles, lines, and labels that make up the right images.

This graphic uses a right-left, given-new structure. In this case, the given information is communicated via prose – the first column provides a summary of the text and introduces information in the center column and right images. The images then communicate the new information on how bitter blockers work.

BB2 also employs a top-bottom, real-ideal structure. The top representations, both in the prose and images, provide information of “what happens” when we taste foods. The bottom part represents what would happen if bitter blockers were in the foods. The graphic therefore does not necessarily provide more detail, but provides information of an ideal situation.

The only framing in BB2 is a dotted line set between the two columns of prose. This separates the prose titled “accounting for taste,” which is an introduction to the right information, and supports the right-left, given-new structure. No framing exists among the prose of the center column and the right images, which provides maximum connection among these elements and separates it from the prose on the left.

BB2 is a relatively simple narration in that it contains few processes overall. The schematic nature of BB2 further underlines the simplicity of this graphic. Though simple, BB2 entails a narrative structure with an embedded conceptual structure. Action processes and geometric symbolism provide the narrative structure of BB2. The dotted curved lines and a dotted vector take the role of action processes. Recall that vectors are one of many indications that a graphic has a narrative structure. The curved dotted lines represent “footprints” of the dark circles – that is, where the dark circles previously were and what path they took to get to the current location. On the other hand the dotted vector represents current or future pathways. The vector is set as a 90 degree angle, and represents the direction of which an object (in this case, a signal) is going. The dotted curved lines and vector take on two narrative roles. The first is the role of an action process (showing past and future directions of movement of an object). They also have the role of geometric symbolism, as the vector represents the entity of a signal and the dotted lines represent past movement of the dark circles.

The dark circles also take on a symbolic process, in which they represent molecules. The use of geometrical shapes, specifically circles and ellipses, to represent molecules is also consistent across both texts. The aspect of small circles representing the particulate is a common way to communicate the micro- and nano- entities.

Together, the role of the dark circles as representing molecules, the graphic’s labels (which represent the possessive attributes each image), and the simple representations of a receptor, all realize the embedded conceptual structure of BB2. Yet due to its simplicity, the conceptual structure also entails what Kress and Van Leeuwen call an unstructured analytical process. That is, though the parts of the graphic are structured, there is no indication of where this representation is situated. The reader must assume that the representations in BB2 "occur" with respect to tasting, and that they show simple schematics of a receptor from a taste bud, on the tongue.

<u>Instructional Description of the Prose and Graphics – *Bitter Blockers*</u>

Instructional Ideas of Bitter Blockers Prose: Analysis of the prose reveals varied instructional ideas throughout this text. At least three major instructional ideas exist, along with many minor instructional details (statements that are not centralized to a major idea). The first instructional idea is that molecules constitute food. This instructional idea runs parallel with one of the main learning goals of the *Smell* unit – that is, all matter is made of atoms and/or molecules. In fact, this text applies the notion of matter being made of particles to a real-world and commonly experienced phenomenon of tasting foods.

The idea that food is made of molecules is first made explicit in paragraph 5, by the phrases, "…breaks food up into single molecules that make up the food." This instructional idea then appears throughout paragraph 5 and continues through the 6th paragraph. In these two paragraphs the word, "molecule" is used 7 times, sometimes alone but most times preceded by different descriptors to distinguish the type of molecule. For example, the text includes "food molecule", "bitter-tasting molecule" (which is inferred as a type of food molecule), and the molecules not normally in food, "bitter-blocker molecule." Note that although the notion of food being made of molecules exists in this text, students must infer that bitter blockers (originally described as "substances" in paragraph 3) are also made of molecules. If a student understands the learning goal of matter being made of atoms and/or molecules, then they may be more apt to make the inference. Otherwise, a reader may find difficulty in making sense of the notion of bitter-blocker molecules as well as the other types of molecules.

A second instructional idea is that how you taste all foods and their flavors (bitter, sweet, etc.) is explained by the way your tongue detects the molecules that make up, and those that are added to, the food. This instructional idea is very general in that it is implied throughout most of the text. A more detailed level of this instructional idea would include the actual process of how one tastes food, which is stated within paragraphs 4, 5 and 6. Without this instructional idea, it may be difficult for a reader to determine the importance of bitter blockers in limiting the amount of bitter flavor being detected.

A third instructional idea is that bitter blockers allow people to eat and/or drink bitter foods and not taste the bitter flavors. Also included in this idea is the implicit notion that bitter blockers, as a substance, can be added to foods. This idea is implied in the last paragraph, by the description of people's reactions to foods that do and do not have added bitter blockers.

Besides these main instructional ideas, the text includes many instructional details. For instance, within the text (paragraph 3) is a list of foods that the reader may have experienced that have bitter flavors. Other instructional details about bitter blockers include: they are a new finding; they are a solution to the problem of tasting bitter flavors; they stop tongue from detecting bitter flavors; they inhibits the detection of bitter flavors by blocking the bitter molecules; that different types exist; and that AMP is one type.

Instructional Ideas of Bitter Blockers Graphic BB1: Due to the conceptual nature of BB1, most of the instructional information it provides is identification of parts of a tongue. The left, person with a tongue, image informs the reader that the object of interest in on the tongue. Taste buds as the item of interest is extrapolated from the graphics header, "Anatomy of taste buds" as well as labels such as *taste bud, taste pore* and *taste cells*. The labels *fungiform, filliform* and *vallate papillae* tell the reader not only where they are located and what they look like when magnified, but also inform the reader that multiple forms of these "papillae" exist. However, no other information about the various kinds of papillae is illustrated.

The captions in BB1 provide instructional ideas, including that papillae cover the tongue's surface, some papillae contain taste buds, and in each taste bud exist many cells. The tongue-papillae-taste bud-taste cells connection that the caption provides is only identified by the labels. Note that in order for a reader to logically make the connections, they must be able to interpret the middle image as a magnified cross-section of the tongue, and that the right image is a rotated and magnified section of the middle image. (The object is rotated 90 degrees left, such that the top of the taste bud in the middle image is the left-most part of the right image.) The rotation of the taste bud might prove difficult for readers, and possibly may confuse readers.

Instructional Ideas of Bitter Blockers Graphic BB2: Due to the narrative structure and labels in BB2, the instructional ideas follow that of two situations. The top image informs the reader what happens when a food molecule settles on, or fits with, a receptor. When this happens, a signal is sent from the receptor to the brain. The second situation is if a bitter blocker is around, and fits into the receptor. If this occurs, then the bitter blocker molecule is taking the space around the receptor, "preventing" a bitter (food) molecule from settling onto that receptor. As a result, no signal is sent.

These ideas are enhanced by the lengthy captions of BB1. These captions also communicate many more instructional ideas that are not directly illustrated in the images. For example, the following italicized phrases in the captions are not connected to the images: "food molecules *mixed with saliva* contact *taste cells through taste cell pores. Taste* receptors *in the cells* then send…*to interpret taste*," and "… bitter molecules, *which have unique shapes*. *The blockers are swallowed with the rest of the food.*"

Description of the Prose and Graphics' Interestingness – *Bitter Blockers*

Potentially Interesting Components in Bitter Blockers Prose: Similar to the *Cooking with Ovens* prose, phrases I identify as potentially interesting are based on theories and suggestions in supporting students' interest. Table 5.5 lists 8 words or phrases from the bitter blocker prose that may be interesting to the students and why. Most of the potentially interesting components of the prose are due to their potential connection to students' experiences. Yet two phrases may spark interest due to a notion of disequilibrium from students' prior knowledge (that you can taste bitter flavors everywhere on the tongue) and novelty (that scientists found bitter blockers – and different kinds of them).

Table 5.5: Potentially Interesting Components of Bitter Blockers Prose

Potentially interesting words and/or phrases	Paragraph number	Why may be interesting
"When people taste something sour, they often make funny faces"	1	Possible relation to students' experiences
List of items that may be bitter; what reader may or may not like	2	Possible relation to students' experiences
"Coffee also has a bitter flavor, which is why some people add milk, cream or sugar…"	2	Possible relation to students' experiences
" specific place on tongue detects each flavor"	4	Possible relation to students' experiences (prior experiences in science class – test flavors on tongue)
"…you can taste each flavor on any part of your tongue."	4	Disequilibrium from prior knowledge
Spit	5	Possible relation to students' experiences
Scientists have found 20 different types of bitter blockers	7	Novelty
"people have tasted grapefruit juice…nasty…tangy but not bad…"	7	Possible relation to students' experiences

Potentially Interesting Components in Bitter Blockers Graphic BB1: BB1 addresses the reader indirectly. "Here the viewer is not object, but subject of the look, and the represented participant [in this case someone holding out their tongue] is the object of the viewer's dispassionate scrutiny. No contact is made. The viewer's role is that of an invisible onlooker…we have…called this kind of image an "offer' – it 'offers' the represented participants to the viewer as items of information, objects of contemplation, impersonally, as though they were specimens in a display case… Here a real or imaginary barrier is erected between the represented participants and the viewers, a sense of disengagement…" (Kress & Van Leeuwen, 2006, p. 119-120) The "offer" characteristic of indirect and objective images tend to be a more "preferred" characteristic for scientific graphics (Kress & Van Leeuwen). However, this "offer" characteristic may also be less engaging for readers due to the lack of interaction involved.

In this case BB1 is different than common "offer" graphics in that it has other characteristics that may support students' interest. For example, though the graphic provides an objective view, the social distance among the reader and graphic is at the intimate and personal level. This is achieved in three ways. First, BB1 does have a "person" involved. Though the person is not looking (the eyes have been cut out of the view) the size and frame of the face makes it as if the person were showing the reader his or her tongue. In fact, the image reminds me of a person opening his or her mouth for a doctor to peer inside. Second, the lack of eyes and other facial features above the nose and ears also sets the picture to be at an intimate and personal distance. Third, readers might identify more with the image of the person with the tongue because the "person" has a general character. In a sense the "person" could be anyone. If more character to the person and/or eyes were added to the image, then a reader might not be able to identify with the representation and may consider the person a stranger, resulting in disengagement. The addition of eyes would also set an "aggressive" social distance, which can also support disengagement with the reader.

BB1 may be interesting to some readers due to its compromise between naturalistic and technological coding orientations. Of the three images in BB1, the left (person with tongue) image and the right (zoom-in taste bud) image have less modality. Alternatively, the middle (zoom-in with layers) image comprises features that make the modality closer to a natural representation. I discussed earlier how the limited modality of the right, person with tongue, image may support interest. Yet the readers may also be interested in viewing what a magnified cross-section of one's tongue really looks like.

From a connection-to-reader viewpoint, the interestingness of BB1 is again due to the left, person with the tongue, image. As shown in Table 5.6, this image is the only part of the graphic that may connect to a reader's experiences. The zoom-in images of the tongue's layers might provoke interest because of its degree of realism. It might also spark interest if students relate the signs and symbols to other objects that they have experienced. However connection to other objects most likely would also promote confusion, or disengagement with the instructional goals of the text.

Table 5.6. Potentially Interesting Components of Graphics BB1 & BB2

Potentially interesting features	Graphic	Why may be interesting
Picture face with tongue	BB1	Social Distance – Intimate and Personal Possible relation to students' experiences
Middle, zoom-in image: layers can look like many different things, "lasagna" (one student also mentioned a forest)	BB1	Degree of realism; similarity of signs/symbols to real-world or experienced objects
Molecules look like balls, bouncing balls	BB2	Similarity of signs/symbols to real-world or experienced objects
Receptor with molecules like a basketball (or similar type of game)	BB2	Similarity of signs/symbols to real-world or experienced objects

Potentially Interesting Components in Bitter Blocker Graphic BB2: Like both *Cooking with Ovens* graphics and BB1, BB2 also provides an objective perspective, and in "offering" information to the reader it is also non-personal. Yet unlike BB1, this graphic contains no person or image to provide personal distance, nor images with any degree of realism, and provides neither context nor background. Also BB1 lacks a point of reference, which may not only be confusing to readers, but may also limit the interestingness of the graphic. The lack of these characteristics first makes BB1 a practically hidden graphic, such that readers may provide limited attention to it. Second, it also limits possible interest in the graphic. Any interest may be dependent on a reader's ability to generate a point of reference themselves. Or, as I indicated in the table, interest may occur if a reader self-generates thoughts of what the images may be similar to, and identify with the graphic in such ways. For example, the graphic to some may look like balls bouncing, and a type of net or goal to which the balls are directed.

Informational Relationships between the Prose and Graphics – *Bitter Blockers*

Tables 5.7 and 5.8 highlight various relationships that the prose and graphics entail. The prose and graphics had both complementary and incompatible ideas. The graphics complement only one part of the text's global structure. The graphics do not illustrate the problem/solution structure, yet both graphics depict background about tasting and the major, alternative, solution of bitter blockers.

Table 5.7. Incompatible Relationships of Prose and Graphics BB1 & BB2

Summary Information by Relationship	How Represented & Comments
Information in Prose Missing in Graphics BB1 and/or BB2	
Bitter Foods; Tasting / Types	[Paragraphs 1 & 2] – tasting bitter foods; types of bitter foods
Dislike of Bitter Foods	[Paragraph 3] – People do not like bitter foods
Tongue – Detection Connection	[Paragraph 5,6] – BB1: shows tongue – taste bud connection; BB2: shows taste bud-detection connection; only together do they represent tongue-detection connection.
Papillae	[Paragraph 5] – "tiny, *pinkish-red* 'mounds' (called papillae)."
Breaking Up Food into Molecules	[Paragraph 5] – "…(your spit) breaks food up into single molecules that make up the food."
Brain Receiving Signal / Taste	[Paragraph 6] – "If the brain doesn't get a signal, then you can't taste the bitter flavors."
20 Types Bitter Blockers	[Paragraph 7] – Scientists have found 20 different types of bitter blockers
Test of Grapefruit Juice	[Paragraph 7] – "people have tasted grapefruit juice…nasty…tangy but not bad…"
New and/or Additional Information in Graphic	
Layers / Parts of Tongue	[BB1] – magnifies tongue to show layers; labels of taste cell, taste pore, papillae.
Taste Cells / Taste Buds	[BB1] – caption: All but the filliform papillae contain taste buds. Within each taste bud there are 50-200 taste cells."
Bitter Blockers (shapes; swallowed)	[BB2] – captions in mid column: "…bitter molecules, which have unique shapes. The blockers are swallowed with the rest of the food."
Palatable	[BB2] – new word
Visual Bitter Blocker Molecule	[BB2] – molecules as dark circles (bouncing balls) [what molecules "look like"]
Inconsistent/Contrasting Information between Prose and Graphic	
Funny Face	[Paragraph 1 : BB1] – "When people taste something sour, they often make funny faces"; BB1: image of person with tongue may be interpreted as making a "funny face"
Where Bitter Detected	[Paragraph 4 : BB1] – "…you can taste each flavor on any part of your tongue."; BB1 tongue, and box on a specific part of the tongue, could be interpreted as where bitter is detected.
Taste Bud / Receptor	[Prose : BB2] – Prose includes "taste bud"; BB2 label "receptor" instead of taste bud

Table 5.8. Complementary Relationships of Prose and Graphics BB1 & BB2

Summary Information by Relationship[a]	How Represented and Comments
Elaboration of Information in Prose	
*Papillae	[Paragraph 5 : BB1] – Middle image illustrates papillae; magnified image implies the "mounds" are tiny; captions use "projections" instead of "mounds"; shows taste buds with papillae.
Similar / Redundant	
Discovery	[Paragraph 3 : BB2] – BB2 caption left column – "new compounds"
Addition of Salt or Sugar	[Paragraph 3 : BB2] – BB2 caption left column – "…hide the taste of bitter foods without adding sugar or salt…"
Location Taste Bud	[Paragraph 4 : BB1] – Both identify taste buds on tongue.
*Saliva & Food Molecules	[Paragraph 5 : BB2] – BB2 caption "food molecules mixed with saliva…"
*Food Molecule Touching Taste Bud / Signal to Brain	[Paragraph 5 : BB2] – BB2 identifies small circle as "food molecule"; shows process of a receptor detecting food molecule, signal to brain; Caption includes: "food molecules…contact…" and "then send signals to the brain to interpret the taste."
*Bitter Blocker – No Signal	[Paragraph 6 : BB2] – BB2 shows a bitter molecule not "touching" the receptor due to the bitter blocker; no signal to brain; Caption includes: "bitter blockers prevent the receptors from capturing bitter molecules."
*Process Bitter Blocker Inhibiting Detection	[Paragraph 5 : BB2] – BB2 shows process of a receptor detecting food molecule (no taste bud); signal to brain; Caption includes: "food molecules…contact…" and "then send signals to the brain to interpret the taste."

a: * = maps to instructional concepts central to the text

The incompatible information represented by this text's prose and graphics mainly entails instructional ideas. Also, as Table 5.8 shows, some of the complementary instructional ideas encompass the *Smell* unit's learning goal of matter as particulate (e.g., breaking up food into molecules and the existence of different kinds of molecules). However two instructional ideas that were not included in the graphics include how food breaks up into molecules and a visual of how different bitter blockers are different types of molecules. These two ideas could have supported readers' understanding of the particulate nature of matter and could help readers comprehension.

Also the incompatible information includes potentially interesting, ideas (e.g., the image of the funny face). Therefore possibly the inconsistent, lacking, or different types of potentially interesting information that each representation portrays may hinder (or at least not promote) students' interest in the entire text.

SUMMARY OF TEXTS & TEXTUAL CHARACTERISTICS

In this chapter I reported characteristics of the prose and graphics for each of the two texts in this study. I did so by using various perspectives, highlighting the visual, structural, instructional and potentially interesting ideas communicated by the prose and each graphic. I also identified relationships between the prose and graphics with respect to the highlighted ideas. In both texts, the prose and graphics have complementary and incompatible relationships. Students' engagement with each text is determined by characteristics of the text such as the possibly interesting components, and/or the incompatible or complementary relationships. In the next chapter I integrate information about the students' characteristics (Chapter 4) and texts' characteristics (this chapter) to describe and better understand ways students engaged with the texts.

CHAPTER 6

FINDINGS ABOUT STUDENTS' PROSE-GRAPHIC ENGAGEMENT

The goal of this study is a better understanding of the ways students engage with prose and graphics as they read and make sense of science texts. The research questions were created to identify trends in the mechanisms behind reading science texts with graphics. In this chapter I describe students' prose-graphic engagement using five approaches. The first approach is a collection of findings focused on students' attention to graphics while reading texts. I identified their attention by their think-aloud comments as well as self-reports of when and why they looked or glanced at a graphic. Reporting patterns about students' attention to graphics provides background useful to understanding students' engagement with the prose and graphics of these texts.

The second approach involves characterizing emergent trends at instances during the reading process in which most students demonstrated attention to the graphics (i.e., popular instances). The third approach focuses on instances in which the prose and graphic are instructionally complementary. The fourth approach involves describing students' engagement with respect to the limitations and affordances of the texts. In this third section I show interactions among students' prose-graphic engagement as they read the *Cooking with Ovens* text, students' individual characteristics, and the limitations and affordances of the prose and MW1. The fifth (and last) approach involves identifying connective features as a prominent factor of students' prose-graphic engagement. In this final section I highlight how students valued, used, and were aware of connective features.

1. DESCRIBING STUDENTS' PROSE-GRAPHIC ENGAGEMENT VIA STUDENTS' ATTENTION TO GRAPHICS WHILE READING

In this section my description of the ways students engage with prose and graphics focuses on their *overall attention* to the graphics while reading. This description entails comparisons of students' attention both across texts and across students. I report patterns regarding how frequently and how consistently students used the graphics while reading as well as why they used them. The patterns I report reflect the ways the 20 students in this study engaged with specific prose and graphics, and provide background to the overall study.

Frequency of Attention to Graphics

All students demonstrated and/or reported attention to at least one graphic when reading the science texts. Table 6.1 shows each student's attention frequency per text, each student's average frequency for the two texts, and the average frequency of attention for each reading achievement group. While reading the *Cooking with Ovens* text, students looked at and/or referred to MW1 and/or MW2 for a total of at least 3, and at most 9, instances. While reading the *Bitter Blockers* text, students looked at and/or referred to BB1 and/or BB2 for a total of at least 2, and at most 8, instances. A student's *average* frequency of looking at and/or referring to the graphics of both texts ranges from a minimum of 3 instances to a maximum of 7.5 instances. The overall average attention frequency among the texts is 5.3 instances. Thus, the students in this study did engage with the prose *and* graphics as they read.

Table 6.1. Frequency of Students' Attention to Graphics

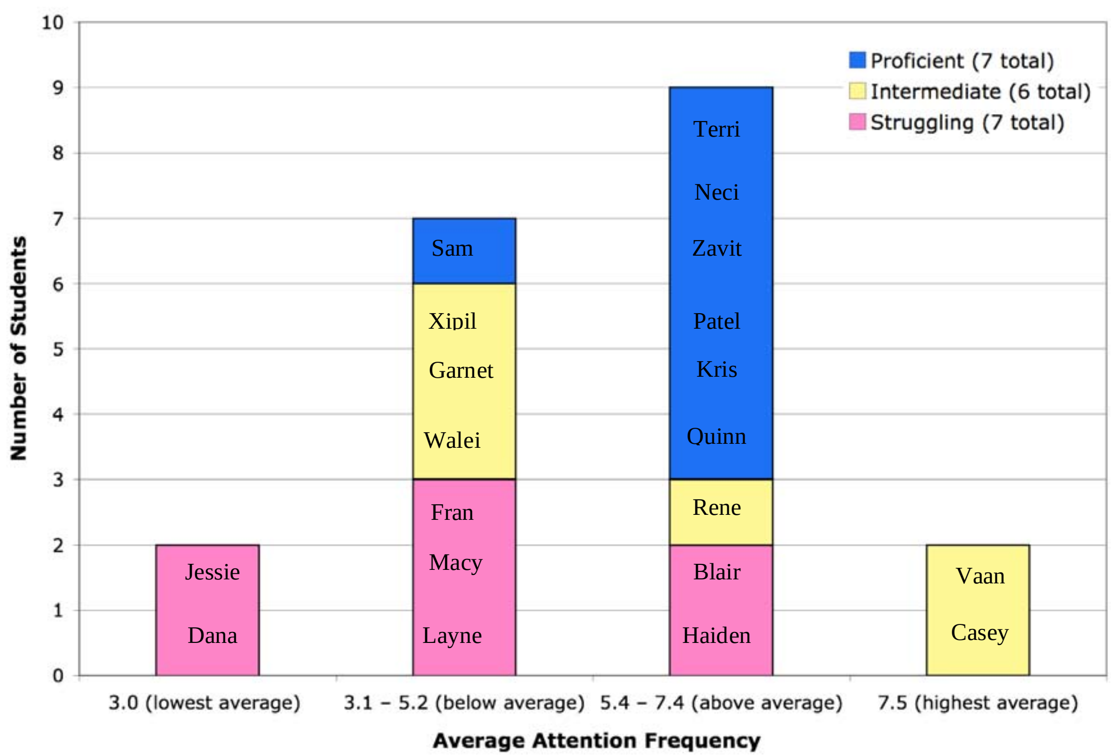
Reading Achievement and Student	Attention Frequency		
	Cooking with Ovens	Bitter Blockers	Average
Struggling Readers			4.4
Dana	3	3	3
Jessie	4	2	3
Macy	6	2	4
Layne	6	4	5
Fran	5	5	5
Haiden	6	5	5.5
Blair	6	5	5.5
Intermediate Readers			5.9
Garnet	5	4	4.5
Xipil	6	4	5
Walei	7	3	5
Rene	8	4	6
Casey	7	8	7.5
Vaan	8	7	7.5
Proficient Readers			5.5
Sam	3	4	3.5
Kris	7	4	5.5
Quinn	6	5	5.5
Patel	7	4	5.5
Terri	6	5	5.5
Neci	6	6	6
Zavit	9	5	7
Average	6.1	4.5	5.3

<u>*Frequency of Attention in Relation to Reading Achievement*</u>

In my study, the struggling readers indicated attention to graphics on average less frequently than the intermediate and proficient readers. The last column in Table 6.1 shows students' average frequencies across texts and average frequencies by reading achievement group. The struggling readers' average attention to the graphics (*M* = 4.4, *SD* = 1.10) was 1.1 times less frequent than the proficient readers' (*M* = 5.5, *SD* = 1.04), and 1.5 times less frequent than the intermediate readers' (M = 5.9, SD = 1.32). The difference between the struggling and intermediate readers was significant: $t(11) = 2.22$, $p = .05$.

I also organized each student's average frequency of attention according to his/her reading achievement (Figure 6.1). In this figure students were grouped according to those who had the lowest average frequency of attention to the graphics, those whose average was below the group average (of all 20 students), those above average, and those with the highest average. As shown in Figure 6.1, most struggling readers were below average in their attention to the graphics. Furthermore, 2 struggling readers, Dana and Jessie, showed the least attention to the graphics. The opposite trend occurred with proficient readers. Most proficient readers were above average in their attention to the graphics. The intermediate readers were split – half of them were below average and the other half above average. Also, 2 of the intermediate readers, Casey and Vaan, showed the most attention to the graphics.

***Figure 6.1.* Average Attention Frequency by Reading Achievement**



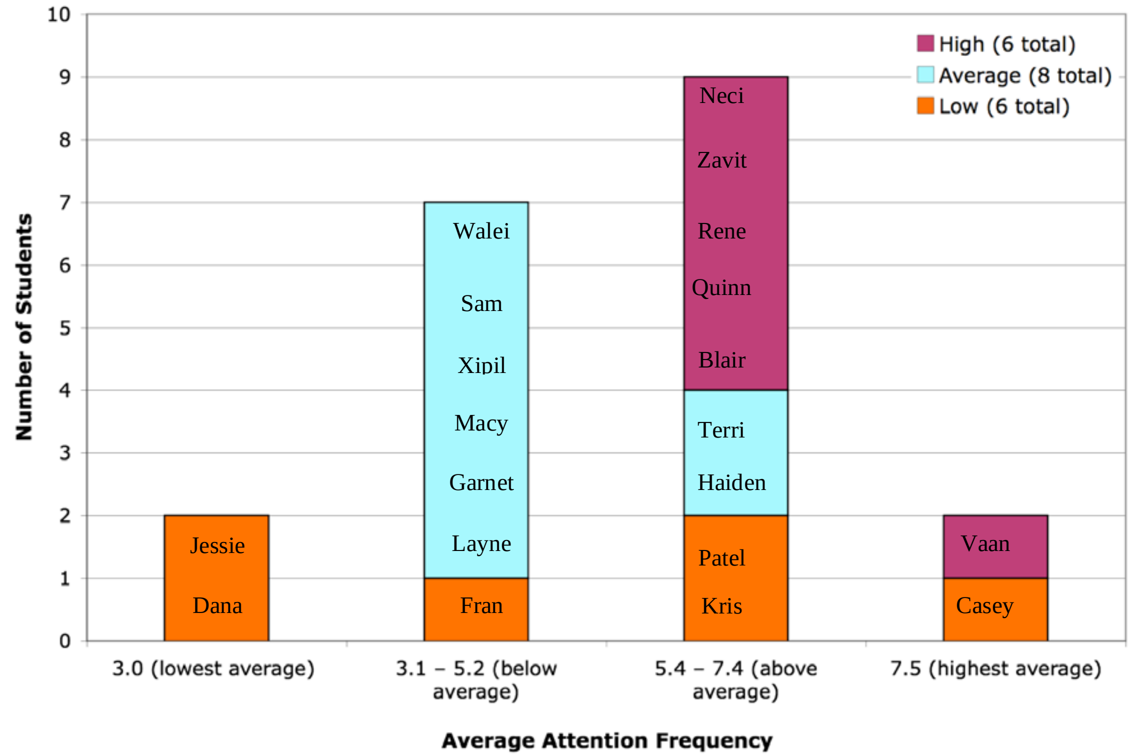
The 2 intermediate readers' frequent attention to graphics and the 2 struggling readers' infrequent attention was most likely the reason why a significant difference existed between the two groups. Yet both the frequency of attention and Figure 6.1 highlight the less frequent attention by struggling readers as compared to the intermediate and proficient readers.

The less frequent attention shown by struggling readers is different from what appears in prior research on students' navigations. In my theoretical framework I described studies suggesting that struggling readers would navigate to the graphics (and therefore engage with the graphics) *more* than intermediate or proficient readers, especially if they had difficulty comprehending while reading the prose in science texts. However in this study, struggling readers' reports of when they looked at the graphics, and their think-aloud comments while reading the texts, suggest less engagement than the intermediate and proficient readers.

<u>Frequency of Attention in Relation to Prior Knowledge</u>

I also organized each student's average frequency of attention according to his or her overall prior knowledge (Figure 6.2). This figure is similar to Figure 6.1 in that students are grouped as being below and above the group frequency average. Overall prior knowledge includes knowledge of the topic for each text (e.g., microwave ovens and taste buds) as well as knowledge of the particulate nature of matter and kinetic molecular theory. Figure 6.2 shows that in this study there was no particular pattern regarding attention to the graphics on the part of students with low prior knowledge. Though the 2 students with the lowest average frequencies also had low prior knowledge, a student with one of the highest average frequencies also had low prior knowledge.

Figure 6.2. **Average Attention Frequency by Overall Prior Knowledge**



However, Figure 6.2 also shows that ***the average prior knowledge readers indicated less frequent attention to the graphics than high prior knowledge readers***. The frequencies of attention for all 6 readers with high prior knowledge were above the average, whereas most readers with average prior knowledge (6 of 8) had frequencies below the average. Comparing these groups via a t-test of means showed that the attention to graphics of readers with average prior knowledge (M = 4.8, SD = 0.71) was significantly less frequent than those with high prior knowledge (M = 6.2, SD = 0.82), $t(12) = 3.67$, $p = .003$.

In Chapter 2 I mentioned research that suggested that those with lower prior knowledge may not use graphics as frequently due to the interaction of content knowledge and the conventions graphics use to communicate information. Prior research has also shown that those with higher prior knowledge use the information in the prose more readily with longer texts, but looked more readily to the graphics when reading shorter texts (Hegarty & Just, 1989). This study is consistent with the research only with respect to the average and high prior knowledge readers. Readers with high prior knowledge seemed to engage with the graphics frequently, and more readily than the average prior knowledge readers. However, in this study, low prior knowledge readers seemed to engage in different ways – they did not follow a specific pattern that would suggest using the graphics more or less frequently than those of average or high prior knowledge.

It also seems that in some cases individual characteristics such as reading achievement were primary factors in students' engagement, whereas prior knowledge was secondary. For instance, the readers with low prior knowledge and below average frequencies of attention were also struggling readers. Furthermore, those with low prior knowledge and attention frequencies above average were intermediate and proficient readers. This interaction among student characteristics as primary and secondary factors of engagement with graphics emerges again later in this chapter.

Frequency of Attention in Relation to the Texts

A difference in the frequency of attention per text exists, suggesting an effect of the text (prose and graphics) on students' engagement with the graphics. Refer back to Table 6.1. On average students looked at and/or referred to the graphics more frequently when reading the *Cooking with Ovens* text (M = 6.1, SD = 1.54) than when reading the Bitter Blocker text (M = 4.5, SD = 1.47). This difference between the texts was significant: $t(19) = 4.38$, $p < .001$. This difference in students' attention to the graphics in the *Cooking with Ovens* text versus those in the *Bitter Blockers* text suggests an interaction between the text (prose and graphics) and students' engagement with graphics in the text. Textual differences were expected, as the analysis of each text (Chapter 5) also illustrated many differences structurally and instructionally, differences by topic and by potentially interesting elements, and differences in affordances and limitations of the prose and graphics in each text.

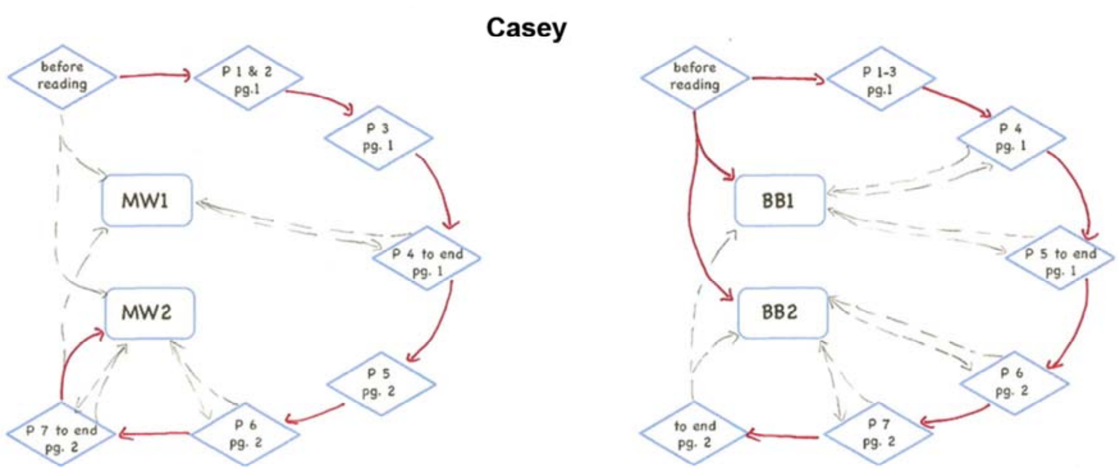
Neci, a proficient reader, also made an exemplar comment about his attention to the graphics as it related to different texts. When I asked Neci when he generally might look at graphics, Neci said he would "sometimes" go back to a graphic after reading, "depending on the article." Neci did not elaborate on what factors might lead him to go back to the graphic after reading. His critical stance may be another indication that other factors in the reading context (such as the type of text, interest and/or difficulty/ease with which students read a text) may interact with students' real-time decisions on whether or not to look at and/or refer to the graphics.

Consistency in Graphic Engagement: Students' Collective Instances of Attention to Graphics

Even with the textual differences, ***about half of the students were consistent across texts with regard to the types of instances in which they engaged with the graphics.*** Consistency was determined by comparing for each text a student's collective instances of attention to the graphics. Consistency occurred when the percentage of similar instances exceeded the percentage of dissimilar instances. Here I use students' maps to illustrate (in)consistency in students' collective instances between the two texts.

Casey was one such reader who was consistent across texts (Figure 6.3). Not only did Casey have one of the highest average frequencies of attending to the graphics, but also Casey's reported looks at, and think-aloud comments about, the graphics occurred in more similar than dissimilar instances throughout the reading process. In Casey's case, the similar instances occurred before reading, within the last paragraph of the first page, within the last paragraphs of the second page, and after reading.

Figure 6.3. **Casey's Maps**



Kris is an example of a student who was *not* consistent in his engagement with the graphics while reading each text (Figure 6.4). Notice in Figure 6.4 how different Kris's attention to the graphics was from one text to the other. Kris reported frequent attention to the graphics while reading the *Cooking with Ovens* text, but reported and demonstrated less attention to the graphics of the *Bitter Blockers* texts. In fact, based on Kris' reported looks at and think-aloud comments about the graphics, Kris was consistent in looking to graphics in only two instances – at the texts' first graphics before reading, and the texts' second graphics while reading the 6th paragraph of each text.

Figure 6.4 **Kris's Maps**

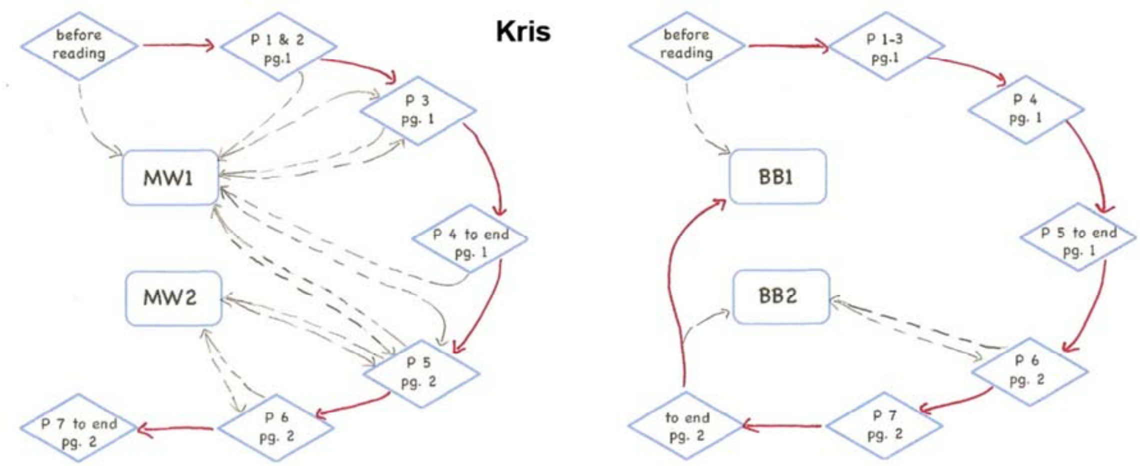
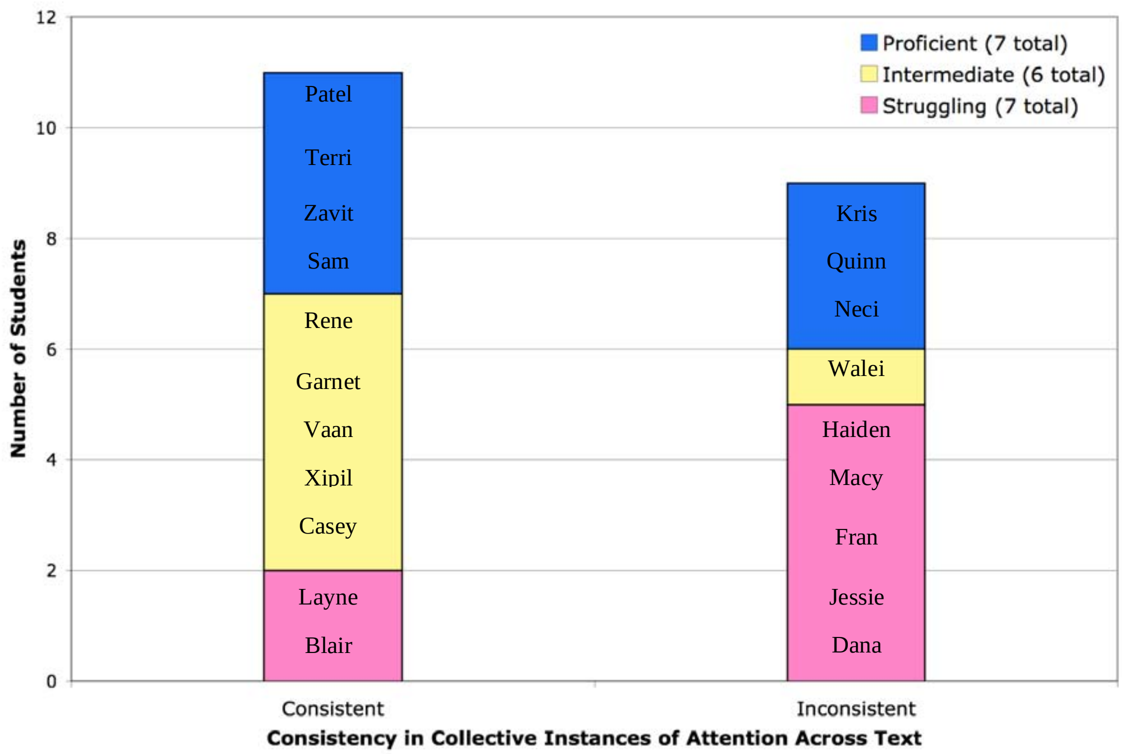


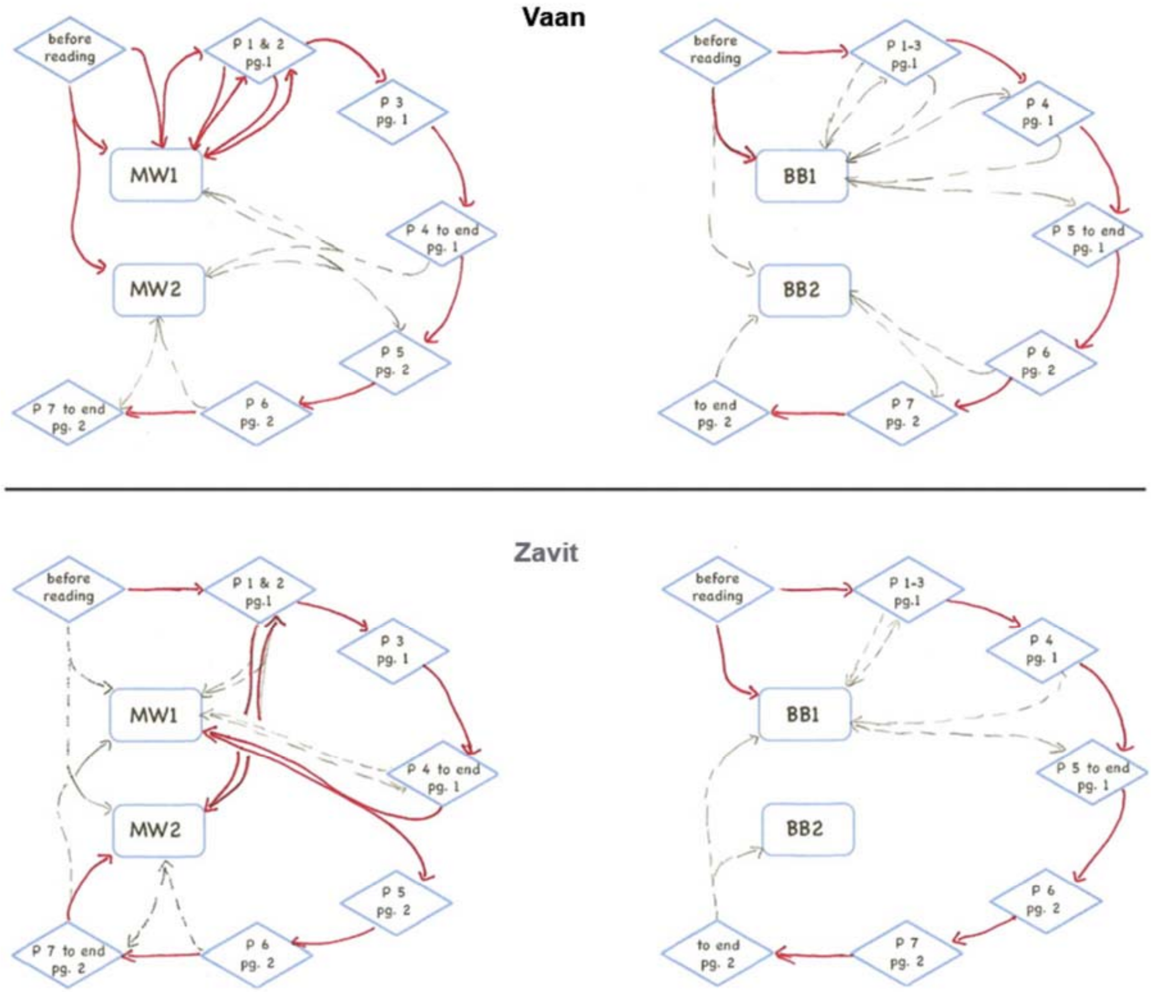
Figure 6.5 shows students who were and were not consistent based on reading achievement group. Notice that few struggling readers (only 2 of the 7) were consistent in their attention to graphics across texts, whereas most intermediate readers (5 of the 6) and about half the proficient readers (4 of the 7) were consistent.

Figure 6.5. **Students Consistent and Inconsistent in their Collective Instances Across Texts**



However, I also found that each of the eleven readers who were consistent were also unique in their collective instances. In other words, the pattern of instances that defined a student's consistency from one text to the next was different than each of the other students' patterns. For example, for both texts, Casey reported and demonstrated attention to one or both graphic(s) before reading, within the last paragraph of the first page, within the last paragraphs of the second page, and after reading (Figure 6.3). Yet Casey's pattern of similar instances was different from the other consistent readers, including Vaan and Zavit (Figure 6.6). Vaan's similar instances included looking at the graphics before reading, frequently looking at and referring to the first graphic of each text while reading the first few paragraphs, and looking at the second graphic around the last paragraph of each text. Zavit's similar instances involved looking at the first graphic before reading, looking to the first graphic while reading the first page of the each text, and looking at both graphics after reading. Like Casey, Vaan's and Zavit's patterns of similar instances across texts were unlike the other readers, and therefore were unique.

Figure 6.6. **Attention Maps of Consistent Students (Vaan & Zavit)**



This analysis of students' consistency, though limited by methods of data collection, illustrates students' possible strategic use of graphics while reading. It indicates that students who do not struggle to comprehend the text but work with the texts to make meanings from them (i.e., most intermediate and proficient readers) may be consistent because they use graphics at specific instances during the reading process, no matter what text is being read. Most struggling students, on the other hand, may not have a routine way of using the graphics, limiting their consistency across texts. Also, the uniqueness of each consistent student's pattern may indicate that, though students individually might engage with graphics in similar ways regardless of texts, individual differences (and the dissimilar ways each individual might engage with the prose and graphics) may dictate that different students look at and/or refer to a graphic at different moments.

Why Students Looked at the Graphics

I also analyzed students' motivations for looking at a graphic for the various instances while they read. Students reported many reasons for looking at the graphics. Seven prominent categories emerged from their reasons.[18] These categories are prominent because more than half the students' responses addressed them. These categories are:

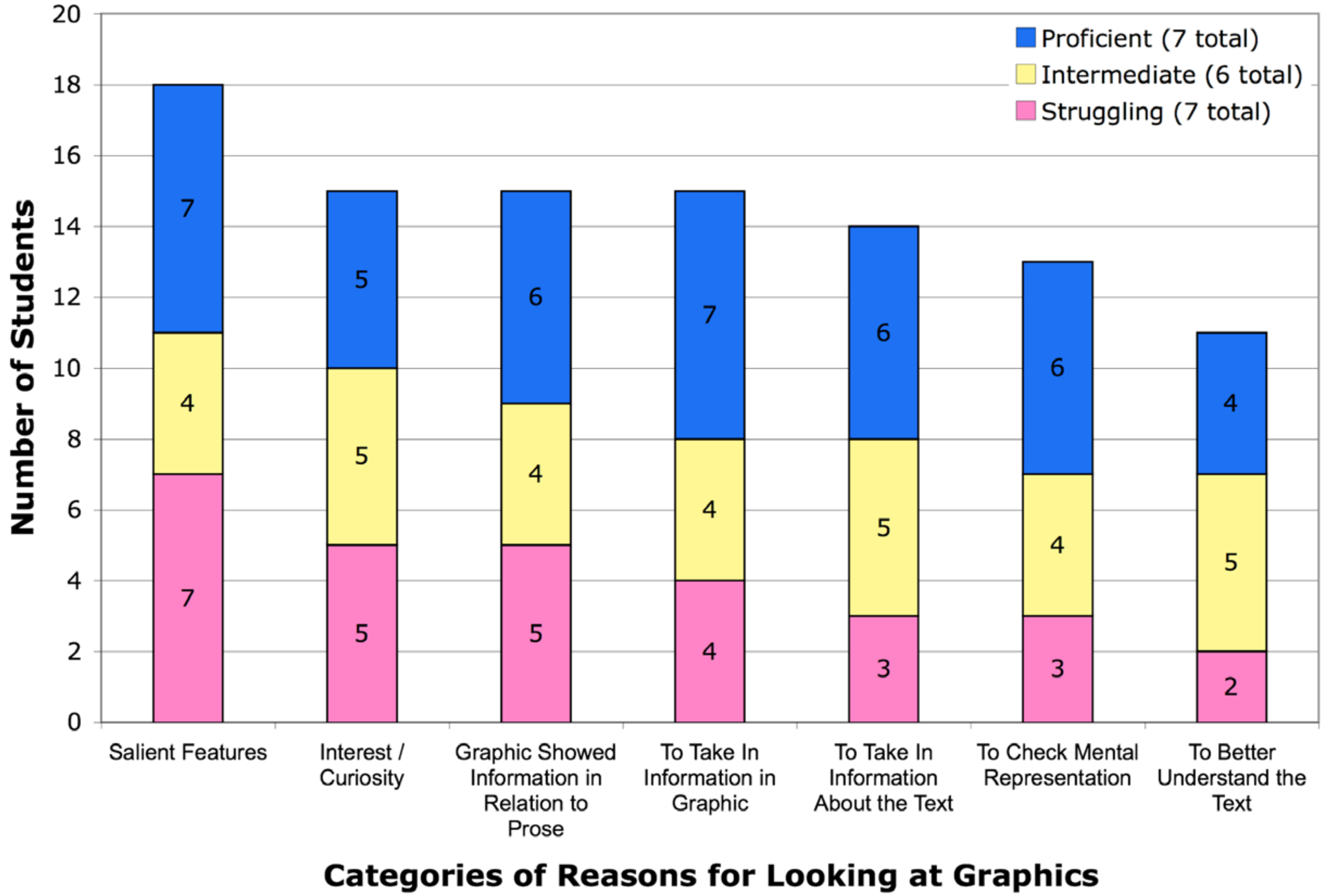
1. because of graphics' salient features
2. because of interest and/or curiosity
3. because graphics showed information in relation to the prose.
4. to take in information in the graphic
5. to take in information about the text
6. to check a mental representation
7. to better understand the text

These categories reflect how students tended to engage with the graphics overall. Also, the categories indicate how, students' strategic uses of graphics were realized.

Figure 6.7 shows the number of students in each reading group who provided reasons in each category. The first four categories were represented in students' reasons, regardless of reading achievement group. The last three categories, however, were represented more often by intermediate and proficient readers, and less often by struggling readers.

[18] The categories are based on accumulation of all students' reported reasons and all graphics.

Figure 6.7. **Prominent Categories Why Students Looked at Graphics**



Categories Represented Regardless of Reading Achievement Group

Because of Graphics' Salient Features: As Figure 6.7 shows, most students mentioned salient features when they described why they looked at a graphic. Salient features include objects in the graphic (e.g., a tongue in BB1), color in MW1, and the size and placement of the graphics (e.g., MW2's positioning in the middle of the page and between paragraphs). Examples of the comments involving salient features include the following:

> Macy: **"**I looked at the other diagram and it's [MW1] in color so it's kind of interesting."
>
> Zavit: "There was a big space in between for the picture, so I was going from here <points to end paragraph 6> to here <points to beginning paragraph 7>. So I looked at it [MW2] because it was right in the middle. It was a big ___ turkey…"
>
> Vaan: "I didn't really know what these things <points to BB2; far right graphics> were, these little things. And they just had like bitter molecules, bitter-blockers and I was reading about it up here."

The salient features are what Peeck (1993) and others consider to be variables known to affect picture-effectiveness. Whether the salient features promoted effectiveness or not, most students (18 of 20) included salient features as a reason why they looked at the graphics.[19]

Because of Interest and/or Curiosity: A student's interest in the text, a specific graphic, and/or the entire reading task depends on various internal and external factors. In this study, interest was another popular reason why students looked at the graphics. Fifteen students included interest and/or curiosity in their reasons for looking at a graphic. Students' comments involving interest and/or curiosity include the following:

> Terri: "Um, I just wanted to see what it [BB1] was about. And it was just showing like about your taste buds and taste cells and stuff."
>
> Walei: "I was just reading and then I would kind of just look over at it [MW1], just because it was like... it looked interesting."

Indeed, most students were interested (or very interested) in the graphics, as reported in Chapter 4. The popularity of looks at graphics attributable to this category aligns with the general understanding that interest and curiosity are important factors in ways students read texts. My study also shows interest and curiosity as an important factor in students'

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[19] Some of the salient features that students identified in their reasons for looking at graphics, such as the tongue in BB1 and the turkey in MW2, are also features I consider "connective features," which I describe the in the last section of this chapter.

looks at graphics when reading science texts. The popularity of this category also highlights the interaction between students' prose-graphic engagement and two possible reader goals: focusing on what interests them and comprehending the text.

Because Graphics Show Information in Relation to the Prose: This third category included many different reasons for looking at a graphic, all of which involved the graphics' illustration of prose-related information. Examples of reasons included in this category include students having a question about the prose and students looking at the graphic because they thought it related to the prose by explaining the prose or containing additional information. For example, students made the comments,[20]

> Patel: "Um, just, um, to... I was like mostly looking at this <points to MW2> part because kind of like showing you the parts of a microwave and like it didn't talk about the parts of the microwave in it before, or in the text."

> Xipil: "Um [sighs] it was, 'when the molecules in the food move faster and the food heats up.' <points to paragraph 6 bottom> And I wanted to see how that was explained also, because I knew that was probably explained here <points to MW2>."

The students' reasons regarding this category demonstrate metagraphical awareness – knowledge that a graphic (should, and in this study, does) illustrate information related to the prose. Further, navigating to a graphic because of this metagraphical awareness indicates the student's strategic prose-graphic engagement, and may therefore be integral to whether or not, and when, a student navigates to a graphic.

To Take In Information in the Graphics: This category encompassed information communicated solely in the graphics. It included students' comments about having another look at the graphic and making sense of information in the graphic. For example, Sam and Patel said,

> Sam: "I just looked at the pictures and read a little bit of it after, to make more sense of the pictures."

> Patel: "…I had already kind of looked at the pictures and tried to figure it out. But I still wasn't completely sure what they were talking about, and I wanted to know what they were talking about. … there could be things I didn't understand in it and like things that weren't in the normal text…"

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[20] The conventions I use within the transcripts for communicating students' miscues in reading and their hand gestures are the following: For miscues, if the reader skips a word or phrase while reading, the prose is crossed out with one strike (e.g., ~~crossed out~~). If a reader says something in place of the skipped prose, the words they say are beside (to the right) of the crossed out phrases. Gestures (such as pointing) are described within <angle brackets>. Also, students' think-aloud comments are labeled by the text (BB for *Bitter Blockers* or MW for *Cooking with Ovens*) and the numbered think-aloud marker (e.g., MW-TA1). Any other think-aloud comments that were not initiated by the markers follow the ~ symbol.

Additionally, as discussed in Chapters 3 and 5, graphics' visual role involves an intricate combination of features that communicate information. Students' reasons that involved taking in information in the graphics may therefore be due to the graphics' visual roles, especially when the science involves nanoscopic concepts. The role of visualizing the science information was apparent. Whether students attended to the graphics or not, students' comments reflected the visual nature of the science ideas and the need to visualize the information graphically. It was most apparent as students asked what a bitter blocker might "look like." Students' reasons that related to taking in information in the graphic may be an indication of students' metagraphical awareness about graphics' visual roles.

Categories Represented Less Often by Struggling Readers

Figure 6.7 also shows other prominent categories of reasons students looked at graphics: checking a mental representation, taking in information about the text, and gaining a better understanding. Notice in the figure that less than half of the struggling readers provided reasons falling into these categories, whereas most proficient and intermediate readers did so. Therefore ***intermediate and proficient readers' strategic movements to comprehend a text may involve checking one's mental representation, gaining a better understanding, and/or taking in information about the text, while struggling readers' strategic movements are less likely to occur in such ways.*** This result aligns with Hegarty and colleagues' report (1991) showing that students *do* use the graphics for such reasons. However, this finding also adds to the research by highlighting that a *difference* seemed to occur among readers. An example of each category includes:

> **To check mental representation:** Kris: "Yeah, I kind of looked back at that [MW1] because when I was reading that <points to prose> I thought about those molecules that kind of like... like when they get heated up and move faster, I kind of thought about that."
>
> **To Better understand:** Quinn: "To understand the rest of it, the rest of the article, because that's what diagrams are meant to do." [regarding MW1]
>
> **To Take In Information about the Text:** Rene: "I looked at it [BB2] for a second while I was thinking about... like thinking out loud. And I was just looking at this for a second <points to BB2> to see exactly how bitter blockers work."

The differences between reading groups indicate that these three categories may be strategies students used to support their comprehension. By failing to use the graphic to check their mental representation, to gain a better understanding, and/or to take in information about the text, struggling students may have been unintentionally limiting their comprehension. And, whether or not intermediate and even proficient readers struggled with prose, they utilized the graphics in these ways, which potentially supported their comprehension.

Better Understanding versus Difficulty Understanding: Based on Hegarty and colleagues' (1991) report that readers might navigate to graphics if and when they have difficulty understanding information in the prose, I looked at students' references to understanding the texts. However the data represented different facets of understanding – *better understanding* and *difficulty understanding.* [21]

Most students, regardless of reading achievement, were aware of the graphics' role as a source of help in making sense of the texts. This finding reflects the readers' use of graphics if they were to have *difficulty understanding* the texts. I asked each student how they might help a fellow classmate read and understand the texts. 16 students (80%) referred to a graphic to help a fellow classmate. This result was consistent with Craig and Yore's (1995) findings based on asking students the same question. (They found that 83% of the 52 students indicated they referred to graphics to help them understand a science text.). As Yore, Craig and Maguire (1995; 1996; 1998) also reported, this result indicates students' awareness of the function of graphics. Students were aware they should use the graphics when they lack understanding and/or if they are having difficulty.

However, students did not demonstrate this awareness in describing why they looked at the graphics. In fact, no students stated *difficulty* (in understanding) as a reason why they looked at the graphics. This was not a surprise since only 3 students expressed difficulty in understanding what they read while reading and since no students reported difficulty in reading and making sense of the entire text. (Any reports of difficulty were about reading single words in the prose.)

[21] Students' comments showed a specific distinction exists between using graphics (a) due to difficulty in understanding and (b) to gain a better understanding. What students may determine as "better understanding," "more understanding," and "making sense" of a text is different from what they consider to be "lack of" or "difficulty in" understanding a text.

However, I did notice that students frequently expressed the tendency to look at graphics to *better understand* what they read. And, as reported earlier, most students who did so in this study were proficient and intermediate readers. Using a graphic for *better understanding* versus *difficulty understanding* seems to distinguish students' awareness of and use of graphics. Most students might be aware that graphics can help if they are having difficulty making sense of the text, and they might even use the graphics in such ways. However, it seems that primarily proficient and intermediate students are aware of, and might use, the graphics to help them *better* understand (i.e., extend and/or clarify their understanding) when already comprehending the text.

Summary: Describing Students' Prose-Graphic Engagement via Students' Attention to Graphics Across Texts and Across Students

In this section, the findings about students' attention to graphics while reading provide background information on their prose-graphic engagement. Students were not only looking at and referring to the graphics while reading, but also paying attention to the graphics more or less frequently based on reader and text characteristics. For example, on average, the struggling readers' attention was less frequent than intermediate and proficient readers, and readers with average prior knowledge tended to look at and/or refer to graphics less frequently than those with high prior knowledge.

I also highlighted that 11 of the 20 students, most (9) of whom were intermediate and proficient readers, showed consistency in their attention to graphics across texts. That is, even though the texts were different, in general the collective instances in which the intermediate and proficient readers indicated attention to graphics while reading were more similar than dissimilar. However, each consistent reader's set of similar instances was unique – each had instances that were similar to each other but were not similar to other readers' instances.

In this section I also described students' prose-graphic engagement by reporting reasons why they looked at the graphics. Most readers' reasons, regardless of individual characteristics, involved the graphic's salient features, interest and/or curiosity, graphics as showing information in relation to the prose, and taking in information in the graphic. Also, my research indicated that intermediate and proficient readers' strategic movements to comprehend a text may involve checking a mental representation, gaining a better understanding, and/or taking in information about the text, yet struggling readers' strategic movements are less likely to occur in such ways. I also reported that regardless of individual characteristics, readers demonstrated a facet of meta-representational competence – metagraphical awareness (as termed by Craig and colleagues (1998)). In other words, students were aware that graphics could help readers who lack understanding and/or are having difficulty with the text. Facets of meta-representational competence are a theme that emerges again later in this chapter and are a focus of discussion in the next chapter.

The findings in this section were based on accumulation of data across all students and both texts as a means to begin shaping an understanding of ways students in this study engaged with prose and graphics when reading science texts. In the following sections I focus on popular instances and complementary instances during the reading process to describe students' prose-graphic engagement.

2. Describing Students' Prose-Graphic Engagement Via Popular Instances

This section focuses on students' prose-graphic engagement at popular instances (where most students navigated to a graphic). ***In this study the students commonly demonstrated and/or reported looking at the graphics at three popular instances in the reading process: before reading (for all graphics), after reading (for all graphics), and around paragraph 6 for MW2.*** For example, Figures 6.3, 6.4 and 6.6 comprise four students' maps, which show that each student indicated looking at the graphics before and after reading the texts. Their maps also show that they looked at MW2 either while reading or after reading paragraph 6. These instances were popular among most students in this study.

Before Reading

All 20 students attended to one or more graphics *before* they began reading the texts. The students attended to the graphic(s) during the pre-reading task and/or just before reading the text. The pre-reading task entailed looking at the text and describing what they thought the text might be about (pre-reading question number 6) and what might be interesting about the text (pre-reading question number 7). For example, when Vaan was asked to predict what the *Cooking with Ovens* passage would be about, he pointed to the graphics.

> Me: Ok. Given that the title of the passage is *Why should I think of molecules when choosing which oven to use to heat my food?* and it includes ideas like ovens and molecules what do you think the passage will be about?
>
> Vaan: Um, I think it will be about... it will just be about telling you what they're used for and how they work.
>
> Me: Tell me more.
>
> Vaan: Like how <points to MW1> molecules work with the food to heat it. And how this <points to MW2; microwave image> works and what's the cycle.
>
> Me: Ok. What do you mean "how this works?"
>
> Vaan: Just how the... how this <points to MW2; microwave image> whole thing works, like the light coming out hits the food and then stays in the food. I don't know, but I think it will just tell me about that.

In this case, even before reading, Vaan was using the graphic as a means to gain information about the text, and to communicate his prediction of the text.

Table 6.2 shows the number of students who demonstrated and/or reported looking *before* reading with respect to each text and graphic. As the table shows, the majority of students indicated attention to at least one graphic in each text before reading (all 20 students for the *Cooking with Ovens* text and 18 students for the Bitter Blocker text). Possibly students used the graphics as cues to predict content of the text and to determine their interest in the text.

The table also shows that most students indicated attention to the first graphics in each text, MW1 and BB1, before students began reading the texts. Attention to these two graphics before reading may be due to saliency and proximity of MW1 and BB1 to the beginning of the prose. Saliency and proximity are considered visual and structural characteristics of the text. This visual and structural pattern may be related to Mayer's (2001) contiguity effect, in which students learn better when the words and graphics are placed closer together and/or presented simultaneously. Possibly students learn more successfully because they are more likely to attend to both modes of representation when words and pictures are close together.

Visual and structural characteristics also emerged in students' explanations of *why* they looked at the graphics before reading. In fact, sixteen readers' reasons involved salient features, a category which includes comments on the graphics' size, color in MW1, and the spatial relationship of the graphics and prose. The salient features category was one of the two most popular categories of reasons given for looking at a graphic before reading.

Table 6.2. Attention to Graphics Prior to Reading

Text and Graphic	Number of Students Who Looked at and/or Referred to Graphic		
	Individual Graphics	All Graphics	At Least One Graphic in Each Text
Cooking with Ovens	–	14	20
MW1	18	–	–
MW2	16	–	–
Bitter Blockers	–	7	18
BB1	18	–	–
BB2	7	–	–
Both Texts	–	6	18

Interest and curiosity together formed the other major factor in students' looks at the graphics before reading. In fact, students' answers to the pre-reading questions show that looking to the graphic to determine interest in the text and/or pointing out the graphic to explain why a text seemed interesting trumped looking to the graphic to predict. Table 6.3 organizes the number and percentage of students who attended to a graphic because of interest and/or prediction. Though students like Vaan (above) used the graphics for prediction purposes, more seemed to attend to graphics prior to reading for determining interest and/or explain their interest.

Table 6.3: Prior to Reading: Number & Percentage of Students Who Used Graphics for Interest and/or Foresight

Graphical Use	Cooking with Ovens (20 total)	Bitter Blockers (18 total)
To determine and/or explain interest	14 (70%)	16 (89%)
To predict and/or gain foresight	8 (40%)	7 (39%)

For example, when I asked Xipil how interested she might be in reading the *Cooking with Ovens* text, Xipil rated her interest at a 4 or 5 (of 5 being very interested), and mentioned her interest in food and wanting to know more. When I further asked her why she chose a 4 or 5 and what about the text might be interesting, Xipil focused on the graphics:

> Me: On a scale of 1 to 5, how interested are you in reading this to find out more about heating food?
>
> Xipil: Probably a #4 or #5 because I like food and I want to know how my food gets heated and if it's safe.
>
> Me: Why do you choose a 4 or 5?
>
> Xipil: Can I say something about like the diagrams?
>
> Me: Sure.
>
> Xipil: Well, it looks interesting to me like this part <points to MW2> because, um, I sort of always wanted to know how microwaves like heat food, because you can't just create heat. There has to be some way.
>
> Me: Tell me about that what you were just saying.
>
> Xipil: Well, because in our light unit we learned that you can't just create energy out of thin air. There has to be some source or whatever. So I think it's you create–, I thought it was used by creating light or using light to heat your food. I think that's part of it, but I wanted to know if there was more to it.
>
> Me: What do you think might be interesting about this text?
>
> Xipil: The diagrams look pretty interesting.

Many students like Xipil seemed to be drawn to the graphics before reading because of interest and curiosity. I earlier reported students' interest in and/or curiosity about the graphics as a common reason why they attended to graphics at any stage of the reading process. Also recall in the theoretical perspective that students' decisions to read a text tended to be based on their interest in the graphics (Halkia & Mantzouridis, 2005). My study supports Halkia and Mantzouridis' conclusions by suggesting prose-graphic engagement before reading can be chiefly due to determining, and reasoning about, their interest in the entire text.

After Reading

All 20 students also attended to one or more graphics *after* reading the texts. "After reading" includes comments made after the student finished reading the text out loud and before the next task began. The attention to graphics *after* reading was more varied and less frequent than *before* reading. As Table 6.4 shows, half of the readers attended to at least one graphic in each text after reading. Interestingly, the second Bitter Blocker graphic (BB2) gained the most attention after reading.

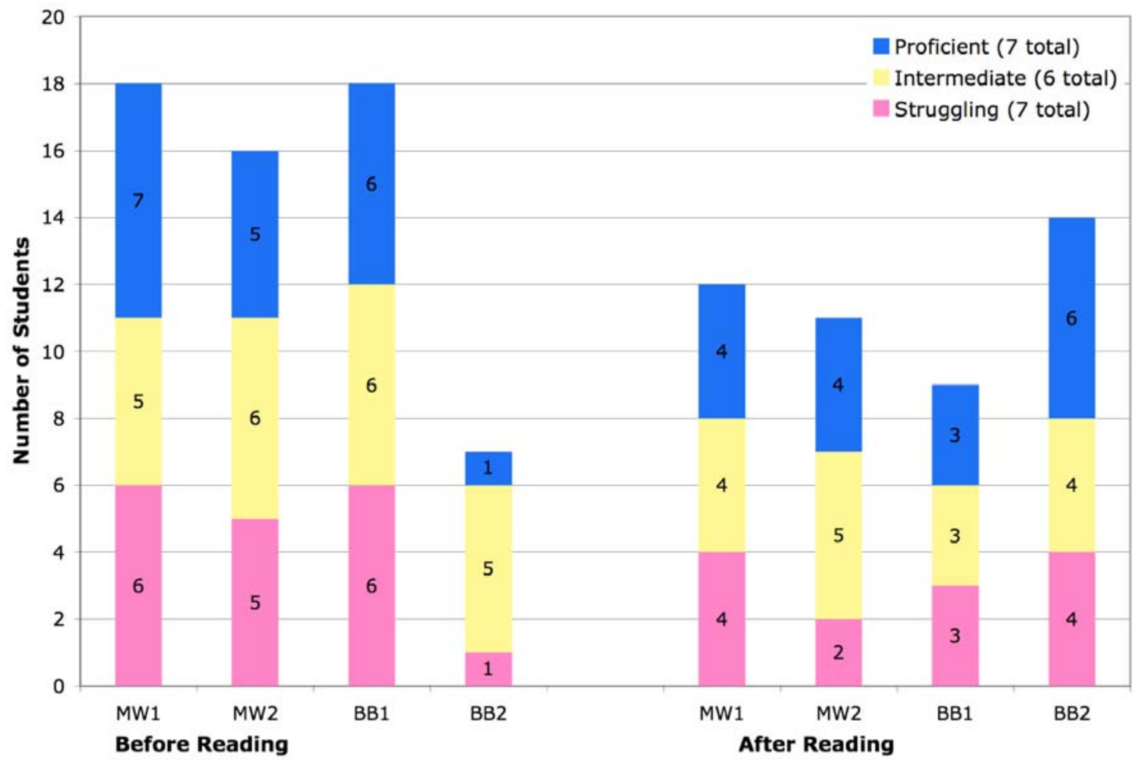
Table 6.4. Attention to Graphics After Reading

Text and Graphic	Number of Students Who Looked at and/or Referred to Graphic		
	Individual Graphics	All Graphics	At Least One Graphic in Each Text
Cooking with Ovens	–	8	15
MW1	12		
MW2	11		
Bitter Blockers	–	7	15
BB1	9		
BB2	14		
Both Texts	–	5	10

Students' attention to BB2 was also greater after they read than before and while reading. This was not the case with the other graphics. Figure 6.8 illustrates the differences in the number of students who indicated attention to each graphic before and after reading. Notice that more students indicated attention to MW1, MW2 and BB1 before reading than after reading. Figure 6.8 also shows the increase in attention to BB2 after reading occurred mainly in more *proficient* and *struggling* readers.

The readers reported various reasons for looking at BB2 after reading. For example, the most common reason students provided was to have another look and/or to study the graphic. That said, only 5 of 14 total students who looked at BB2 after reading provided that reason. For the most part, the reported reasons differed widely.

***Figure 6.8.* Attention to Each Graphic Before and After Reading**



Possibly most students attended to BB2 after reading because of the structure and placement of the graphic as well as the cognitive effort needed to engage with the graphic. In just finishing the task of reading, students had, and were continuing to, make meaning and comprehend what they had read. After reading may have therefore been the most efficient time to look at BB2. For example, Vaan's reason for looking at the graphic after reading was because of interest, because he had more time to take in what the graphic was showing, and because he wanted to make more sense of it: "Um, it just looked interesting. Like these things <points to BB2>. Plus I was done and while you were writing down stuff, it just seemed like a good thing because I wanted to know what it was about but I didn't have time to go through this one." The required time and cognitive effort as demonstrated by Vaan's comment may explain why 5 of the 14 students reported looking at BB2 afterwards to have another look and/or to study the graphic.

The cognitive effort needed to engage with the graphic may relate to the amount of prose beside the graphics (e.g., in the case of BB2, the lengthy captions). For example, Sam looked at BB2 after reading because she had not done so previously. When I asked Sam why she looked at BB2 after reading, she said, "Well, I didn't really read any of it before. I just looked at the pictures and read a little bit of it after to make more sense of the pictures." By saying "read" Sam seemed to mean the prose in BB2. This also seemed to be the case with Fran. When asked why she looked at BB2 after reading, Fran provided a reason showing her focus on the captions and prose in BB2; "Um, because I was done and I wanted to see right here <points to prose in BB2>…see what it said." Fran's focus on the graphic's prose also illustrates how the structure of the graphic (including the small images and the prose to the left of the images) might lead readers to look more closely at BB2 after reading: any instance while reading might have been too difficult cognitively.

<u>While Reading Paragraph 6, and between Paragraphs 6 & 7 with MW2</u>

The third popular instance was to look at MW2 while reading the sixth paragraph, and between paragraphs six and seven of *Cooking with Ovens*. 19 of 20 total students in this study reported and/or demonstrated looking at MW2 at this instance. The apparent visual layout and placement of MW2 with respect to the rest of the *Cooking with Ovens* text most likely explains the popularity of students' looks at MW2 after they read paragraph six. In a sense, the graphic is difficult to avoid when reading and following the linear flow of the prose from the top to the bottom of the page. This factor of MW2's popularity was evident in students' reported reasons why they looked at MW2 at this instance. The most popular reason for looking at MW2 at this instance was its saliency. In fact, 12 students' reported reasons about MW2's saliency included identifying objects in the graphic and/or recognizing MW2's spatial relationship with the prose.

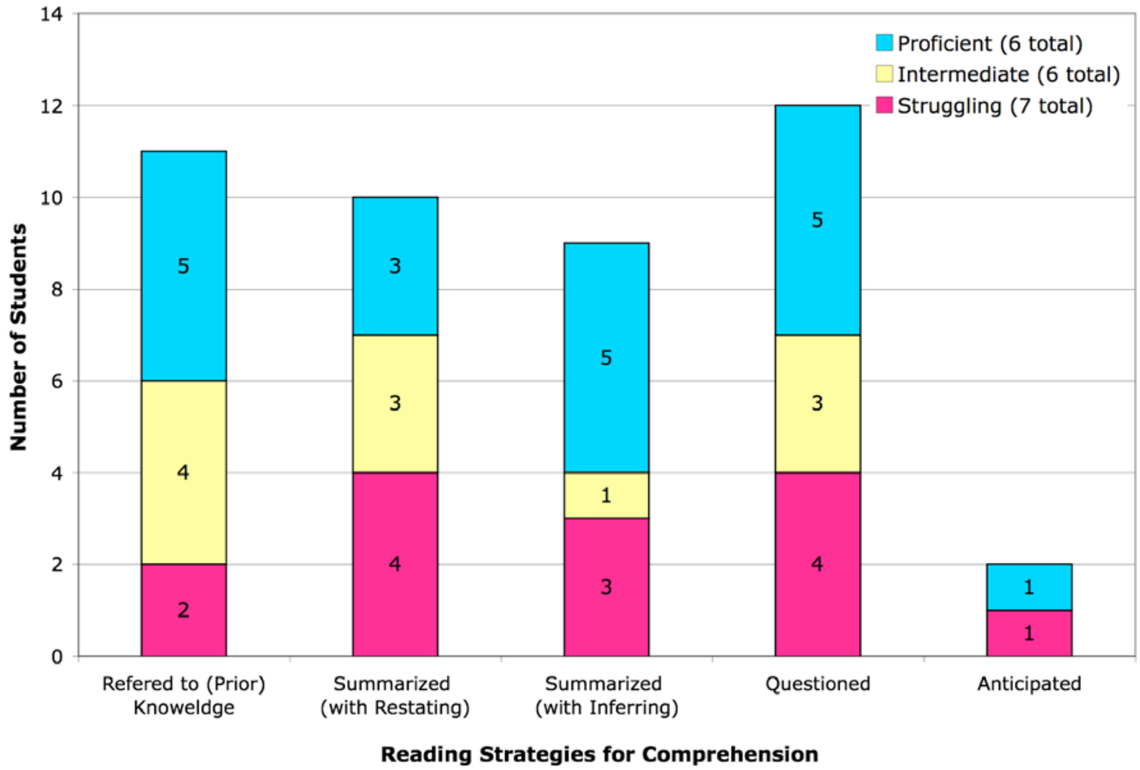
The layout and placement were also indicated by 4 readers as factors in MW2's popularity around the sixth paragraph. These readers finished reading the paragraph, then read and/or interpreted MW2, and then continued reading the seventh paragraph. (As a reference, only 6 total readers stopped reading the prose to read and/or interpret a graphic before afterwards continuing their reading of the prose. Therefore, among those who did so, the majority stopped reading the prose to interpret and read the captions of MW2 at this instance.)

Also emergent at this popular instance were two general mechanisms by which students tended to use MW2. Based on students' think-aloud comments, ***students seemed either to apply their use of both the graphics and reading comprehension strategies together to make sense of the text or use reading comprehension strategies while focusing solely on interpreting and making sense of the graphic.*** These mechanisms were apparent in students' think-aloud comments at various points as they read the texts, but it was most noticeable when students looked at MW2 around paragraph six.

Students' think-aloud comments showed that they were applying reading comprehension strategies (i.e., questioning, summarizing, anticipating and referring to prior knowledge) at the moments they looked at and/or referred to a graphic. Figure 6.11 shows the number of students whose think-aloud comments involved use of various strategies as they looked at MW2 around the sixth paragraph.[22] (This excludes Sam, a proficient reader and the only reader who neither demonstrated nor reported looking at MW2 at this instructionally complementary instance.)

[22] I identify students' use of reading strategies, but I do not report here assessments of the quality of the strategy use (e.g., whether the summary included just details or instead included relationships).

Figure 6.9. **Number of Students Who Demonstrated Each Reading Strategy as They Used MW2**



Neci's comments as he read the sixth paragraph provide an example of ways students used the graphic in conjunction with reading strategies. Neci's think-aloud comment involved summarizing the prose by integrating what he had just read with information he read earlier in the text and then incorporating information from the graphic:

> [reads]: The microwaves make the water molecules move back and forth faster (they move back and forth about a million times a second!). All of the faster-moving water molecules in the food then collide with the rest of the food molecules.
>
> ~MW-TA11. So I'm like... water is making the other molecules move around faster. And the oven <points to the end of 1st page> makes everything <moves hands around in the air above text – both hands shaking back and forth>, water or not, move faster and the water has to move faster in a <points to MW2> microwave I guess. [continues to read]

In this case, Neci seemed to use the graphic as a visual tool when summarizing what he read. Layne's comment as he read the sixth paragraph is another example of how a reader might utilize the graphic and reading strategies together:

> [reads]: When you turn on a microwave oven, a device in the oven makes microwaves. The microwaves reflect off the walls of the oven, and move in the oven in all directions.
>
> ~MW-TA9. I thought that microwaves probably comes out of something. Like if you cut open a piece of meat, they probably come out of the meat. If they get trapped in it, that's probably why smoke comes out of it. [continues to read]

Layne's comment shows that he was making sense of the ideas he read, as well as incorporating an interpretation of the graphic. In this case Layne was doing so in conjunction with making inferences about, and possibly clarifying, what microwaves do when heating food.[23] Layne made some incorrect notions about microwaves, but this example nonetheless shows another way readers can use reading strategies and the graphics together to make meaning of a text. Possibly use of reading strategies and graphics together occurs because graphical representations, in being external and having information easily accessed, act as "external storage of information," thereby "freeing up working memory resources for other aspects of thinking" (Hegarty, 2011, p. 450).

Readers also used the graphics in a different way, which I call *distinct use* in order to separate it from the previous mechanism (which seemed to be a joint use of graphics and reading comprehension strategies). Distinct use of graphics tended to involve using strategies to interpret the graphics and/or elements in the graphic. For example, Terri began to read through MW2, but then stopped to make sense of "microwaves," saying,

> [reads]: That makes *all* of the food molecules move faster. When the molecules in the food move faster, the food heats up.
>
> ~MW-TA12. Um, [under breath: The food heats up] [pause] All right, so it, um, kind of sounds like that when like, um, a new [pause]... when like the molecules actually in the food move faster. The faster they move the hotter like the food is going to get, because they were saying stuff about like when the molecules in the food move fast like the food heats up, so. Microwave [pause]. Ok, I was just reading the graph and it like [pause]... Ok, number one doesn't make sense either. "Magnetron produces microwaves." Well, I mean, does the magnetron like heat– like make the heat in the microwave or anything like that? Because it doesn't really say it. "Stirrer disperse microwaves in oven. Water molecules in the food absorb microwaves." Mic-ro waves... hmm
>
> Me: What are you thinking?

---

[23] Note that Layne begins his think-aloud with, "I thought that." Initially one would interpret this as referring to prior knowledge (e.g., identifying what he thought about microwaves before reading the section). However, Layne consistently began his think-aloud comments with, "I thought," which has led me to instead interpret it as his preface to describing what he thought while reading the statement (i.e., his way of "thinking aloud" what "he thought") and not as referring to prior knowledge.

> Terri: I don't know because like the microwaves kind of sound like, I don't know– like two different words.
>
> Me: Keep on– explain what you're thinking.
>
> Terri: I was just like... to try to make it make more sense to me, I tried to break it into two words. But now it doesn't even make any sense. I split them to "micro" and "waves," but that would kind of be like small waves or something, but that doesn't really make sense either. Um, so. [continues to read]

In this example Terri was asking questions, yet the questions were in regard to her interpretation, decoding, and sense-making of the information *in the graphic*. Cognitive strategies readers used when focusing on interpreting solely the graphic seemed to be directed toward making sense of the graphic by itself, and only indirectly pointed toward comprehending the text. Possibly this focus on the graphic alone was instead a distinct step in accessing information, though application and integration of information from the prose and graphics could have been occurring as the distinct processing occurred. Distinct use of graphics tended to occur less frequently and tended to involve either students reading through the captions in a graphic or students focusing on an element in the graphic.

I highlight the two general uses of graphics here because, as the theoretical perspective showed, many studies focused on understanding students' comprehension strategies of each representation (the prose and graphic(s)) individually, whether the focus was only on one representation or on both. However, with respect to this study's context of asking students to read science texts as they normally would, such a segregation would have limited understanding of how students use graphics when reading science texts. For example, in this study graphic use seems to be related to Hegarty's (2011) description of "external storage of information" such that readers can utilize the graphic and reading comprehension strategies (such as summarizing, referring to prior knowledge, anticipating, and asking questions) together. Focusing only on the reader's use of graphics as a reading strategy might also have limited understanding of how students use graphics when reading science texts. Even though few students seemed to apply strategies to interpret solely the graphic, this use of strategies should not be ignored. These findings show that the two general uses of graphics might be best utilized together as a means to support students in reading texts with prose and graphics (as discussed in the next chapter).

Summary: Students' Prose-Graphic Engagement Via Popular Instances

In this section the descriptions of students' prose-graphic engagement entailed a focus on popular instances. Three instances emerged as popular instances in which to look at a graphic: before and after reading (for all graphics) and around paragraph 6 for MW2. For each of these instances the structural and visual characteristics of the prose and graphics (including placement of the graphics and salient features) seemed to be prominent in explaining the popularity. Each instance also involved other factors that may explain individual popularity, such as interest, cognitive efforts to engage with the graphics, and complementary relationships of the graphics to the prose. I also used students' think-aloud comments around the conjunction of paragraph six and references to MW2 to show that students seemed to either jointly use the graphics and reading comprehension strategies (e.g. questioning, making inferences) or demonstrate a distinct use of strategies to interpret solely the graphics. However, in each case the student could have been integrating the information from the prose and graphic.

I continue to describe students' prose-graphic engagement in the next section, as I focus on students' engagement during instructionally complementary instances.

3. Describing Students' Prose-Graphic Engagement Via Instructionally Complementary Instances

Prose and graphics are instructionally complementary when both representations together communicate the central instructional concepts of the text. Recall in Chapter 5 I identified the complementary relationships that communicated the instructional themes of each text. The relationships included elaborations and similar/redundant information between the prose and each graphic. Table 6.5 lists the instructionally complementary instances by specifying the paragraph number that included the specific instructional concept and the graphic that also communicated the information.

Table 6.5. Instructionally Complementary Instances for Each Text

Text & Paragraph Number	Graphic	Instructional Ideas Communicated by Each Representation
Cooking with Ovens		
Paragraph 3	MW1	Increased Movement of Molecules; Collisions; Movement Molecule/Food Heating Connection
Paragraph 4	MW1	Increased Movement of Molecules; Collisions; Movement Molecule/Food Heating Connection; Faster Moving Molecules Begin at Edges/Outside to Inside Process
Paragraph 6	MW2	Microwaves Moving; Movement Molecules; Process of Microwaves in Oven; Microwaves Absorbed
Bitter Blockers		
Paragraph 5	BB1	Papillae are the Mounds – this is where taste buds located
Paragraph 5	BB2	Saliva and Food Molecules; Food Molecule Touching Taste Bud / Signal to Brain; Process Bitter Blocker Inhibiting Detection
Paragraph 6	BB2	Presence of Bitter Blocker Leads to No Signal to Brain

As I mentioned in the theoretical perspective, meanings of the central instructional concepts can be "multiplied," or at least meanings can be developed from each representation – that is, if students access the information. Students' prose-graphic engagement in instances during the reading process when the graphics and prose complement each other therefore may promise a more comprehensive understanding of the texts' central instructional ideas. I therefore looked at students' attention to the instructionally complementary instances, and I characterized emergent patterns of students' engagement in the instances based on their think-aloud comments.

<u>Students' Attention to Graphics in the Complementary Instances</u>

Overall, ***attention to the graphics in the instructionally complementary instances paralleled prior knowledge and reading achievements.*** Of the six total instructionally complementary instances, students looked at and/or referred to the graphics at least once (17% of the instances) and at most five times (83% of the instances) while reading. Figure 6.9 shows the students who indicated attention to the graphics in more than half of the instructionally complementary instances (four to six of the six total instances). Figure 6.10 illustrates the students whose attention to the graphics occurred at half or fewer instances (zero to three of the six total instances). In both figures, students are grouped by reading achievement (columns) and by overall prior knowledge (shades).

Figure 6.10. **Students' Attention to Graphics in More than 50% of the Instructionally Complementary Instances**

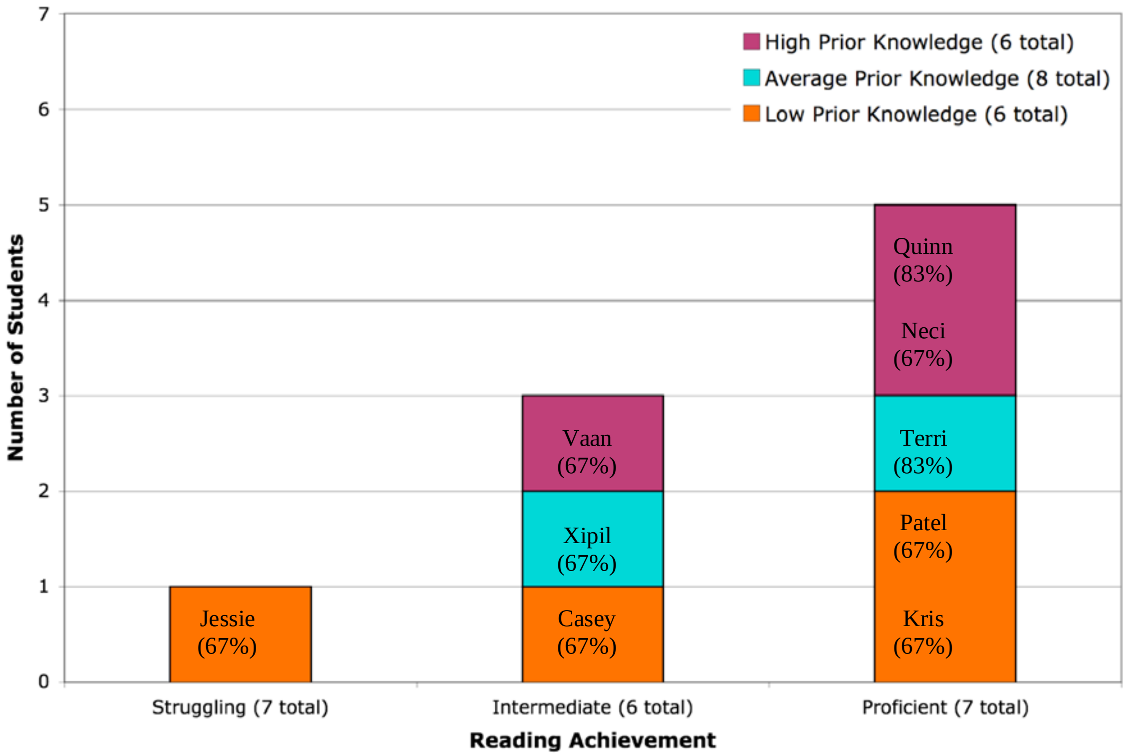
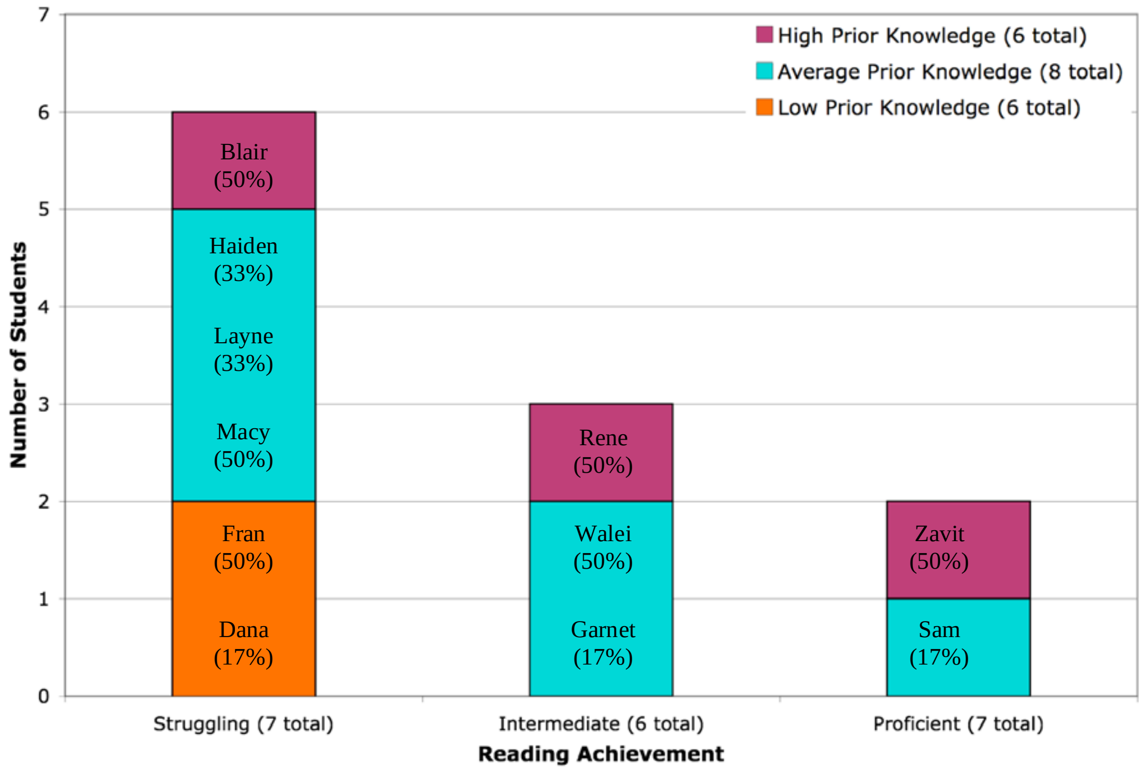


Figure 6.11. **Students' Attention to Graphics in 50% or Fewer Instructionally Complementary Instances**



A direct relationship seemed to occur between students' reading achievement level and their attention to the graphics at instructionally complementary instances. Of the 9 students who indicated attention to the graphics in more than half of the instructionally complementary instances, only 1 was a struggling reader, whereas 3 were intermediate readers and 5 were proficient readers (Figure 6.9). Of the 11 readers who looked at and/or referred to the graphics in half or fewer instances, most were struggling readers (6), and the least were proficient readers (2; Figure 6.10). This relationship suggests that a poor reader may be less likely to engage with both the prose and graphics in such instances, and a proficient reader may be more likely to engage with the graphics in the instructionally complementary instances.

However, an inverse relationship appeared in my study when I looked at the relationship between graphics engagement in instructionally complementary instances and prior knowledge level. Most students with low prior knowledge (4 of 6 students) tended to engage with the graphics in the instructionally complementary instances, whereas those with average prior knowledge (2 of 8 students) tended not to do so.

Comparison of the percentage of students who represented each prior knowledge level in Figures 6.9 and 6.10 reflect this relationship. Table 6.6 also displays this comparison. Of the 9 students who indicated attention to the graphics in more than half the instances, 4 had low prior knowledge, 2 had average prior knowledge, and 3 had high prior knowledge. Not only did most of the low prior knowledge students engage with the prose and graphics in more than half of the instances, but they also made up about of half of the total number of students who indicated attention to graphics in four to six of the six instances. The opposite occurred with the average prior knowledge students. Of the 11 students who indicated attention to the graphics in half or fewer instances, 2 had low prior knowledge, whereas 6 had average prior knowledge and 3 had high prior knowledge. Notice also that no trend emerged regarding students with high prior knowledge. The differences between readers with low and average prior knowledge suggest that students with little knowledge of the science text topic may be more likely to engage with the graphics. However students who have average prior knowledge may not engage with graphics as readily.

Table 6.6. Students' Attention to Graphics in Complementary Instances with Respect to Prior Knowledge

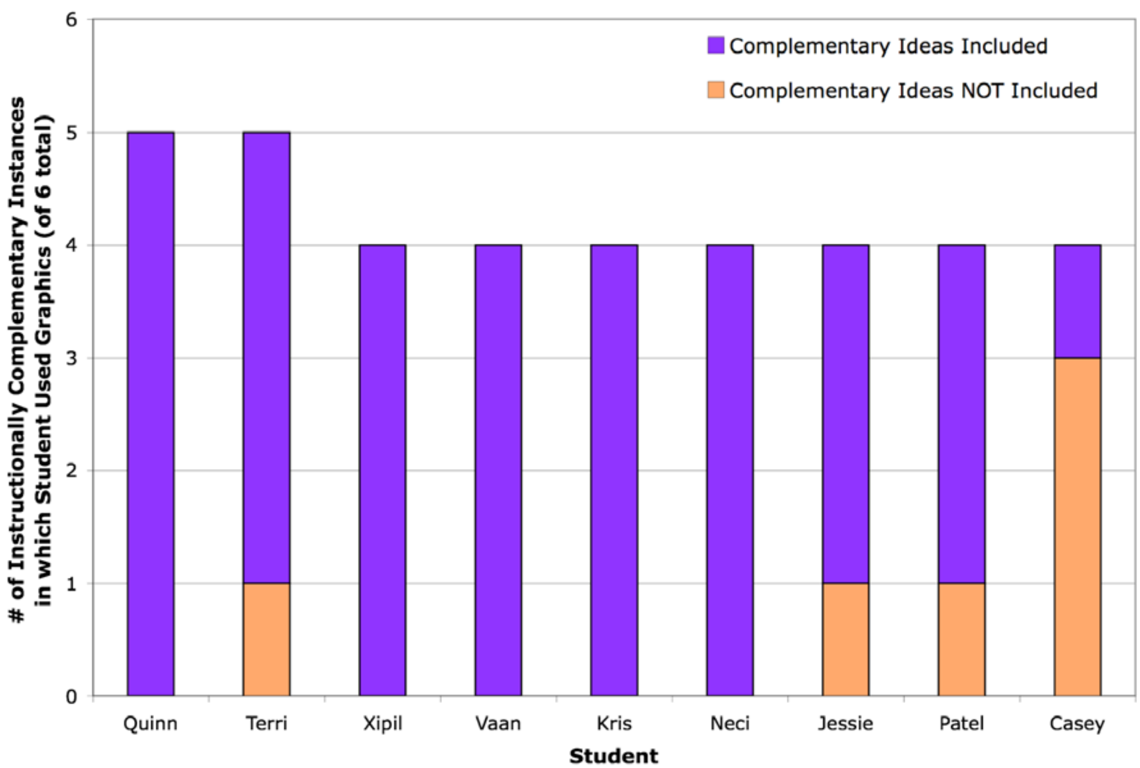
Students' Attention to Graphics	Prior Knowledge			Total
	Low	Average	High	
# Instructionally Complementary Instances				
More than Half (4-6):	4	2	3	9
Half or Less (0-3):	2	6	3	11
Total	6	8	6	20

The pattern between those of low and average prior knowledge may be a factor in the intermediate and proficient readers' use of graphics in instructionally complementary instances, but it may not be a prominent factor in struggling students' engagement with prose and graphics in such instances. As Figures 6.9 and 6.10 show, the 3 intermediate and proficient readers with low prior knowledge looked at and/or referred to the graphics in most instructionally complementary instances. However, of the 3 struggling readers with low prior knowledge, only 1 engaged with the prose and graphics in most instances (Figure 6.10).

Students' Prose-Graphic Engagement in Instances in which They Indicated Attention to Graphics

I analyzed the think-aloud comments of the 9 students who indicated attention to the graphics in more than half of the instructionally complementary instances (i.e., students in Figure 6.9). I determined the extent to which each of the 9 students' think-aloud comments included instructionally complementary ideas. I found that ***8 of the 9 students who indicated attention to graphics in most instructionally complementary instances demonstrated they were making sense of the complementary ideas found in those instances.*** Figure 6.11 illustrates the number of instructionally complementary instances in which each student used the graphics (of six total instances). The figure also shows the number of instances in which each student's think-aloud comments included the complementary ideas.

Figure 6.12. **Number of Instances in which Think-Aloud Comments Included Instructionally Complementary Ideas**



Of the 9 students, 5 included instructionally complementary ideas in all of the instances in which they indicated use of the graphics. Three students included complementary ideas in most of the instances (Terri included complementary ideas in four of five instances; Jessie and Patel included complementary ideas for three of the four instances). Only one student (Casey) included instructionally complementary ideas in few instances (one of the four in which he indicated attention).

<u>Students' Engagement with the Prose When They Did Not Utilize the Graphics</u>

Three characteristics emerged regarding the students who indicated attention to the graphics in half or fewer of the instructionally complementary instances (i.e., those in Figure 6.10) and regarding their engagement with the prose in the complementary instances when they did not utilize the graphics. (1) Some students who missed the opportunities showed signs of difficulties, such as confusion or disengagement with the reading task. (2) Other students seemed to have been making sense of the text or working through the text, but made comments and/or asked questions about the science information that the graphic provided. (3) And still other students seemed to have been comprehending and engaging with the prose, summarizing information they read, correcting and/or adding to their previous ideas, and even questioning beyond the text.

The first characteristic (signs of difficulty and disengagement) was identified only in struggling readers. In fact, the proficient and intermediate readers showed neither signs of struggle nor confusion in their think-aloud comments. The second characteristic (comments and questions related to the supporting graphic) was most noticeable in the 3 intermediate readers but was also identified in 1 of the struggling readers. Readers at each reading achievement level seemed to demonstrate the third characteristic (signs of comprehension and engagement). However, this characteristic was most apparent whenever a proficient reader engaged with the prose in instructionally complementary instances.

Fran, Dana, and Layne were the students who showed signs of struggle with the texts. Fran was a struggling reader who comprehended neither the *Cooking with Ovens* nor the *Bitter Blockers* texts. Fran's prior knowledge of molecules was average (i.e., she had demonstrated some knowledge of molecules that students are expected to learn in the middle school years). Also, based on assessments of prior knowledge (Chapter 4), Fran had low prior knowledge of microwaves and ovens. In her think-aloud comments, Fran focused on syntax and errors in the text. Fran indicated attention to the graphics at three of the six total instances. Her use of graphics included looking at MW1 around the instructionally complementary instances. Yet due to the extent of her struggle with the text, coupled with the complexity of the graphics, I question whether attention to the graphics would benefit her access to, understanding, or even internalization of the instructionally complementary ideas within the prose and graphics. In short, Fran's comments suggest she was not even focusing on the science ideas communicated by each mode. The following excerpt is an example of Fran's difficulty:

> [Reads]: The hot air in the oven then heats the food. Fast-moving molecules in the air ~~collide~~ cool-id– coolid? [laughs] coolid with the food molecules.
>
> ~MW-TA5: I'm not thinking of anything.
>
> [Reads]: The ~~collisions~~ conclusions make the food // molecules jiggle faster. So the food molecules get more energy from the hot air molecules surrounding the food, and the food gets hotter. [skips MW-TA6] You might have noticed that when you take pizza out of the oven too early, the inside of the pizza is still cold. It takes time for food to //
>
> ~ Oh, "become" – I thought that said because, because it's– that <points to "become" on one line> – that <points to "because" on next line right under "become">. OK.
>
> [reads]: become warm all the way to the center. That is because in a regular oven, all of the food molecules don't move faster at once. The ones on the outside edges of the food start moving faster. Then they ~~collide~~ coll-id? with the food molecules on the inside, making the inside food molecules move faster. [skips MW-TA7] It takes a long time because the food molecules are ~~colliding~~ colding one by one, //
>
> ~ [under breath] colding, colid-ing. What?

Fran's comments show that she could not read the word *collide*, an important word to understand in order to make sense of the underlying science concepts and to comprehend the text. As I mentioned in Chapter 5, the notion of *collide* as described in the prose is shown in MW1 as the curved arrows pointing from one small circle (i.e., molecule) to another small circle. However, this representation is limited – it could be interpreted in many ways that are different from a *collision*. For example, arrows could be interpreted as molecules "spinning" or moving to the next molecule, with no actual *collision* taking place.

A similar situation occurred again with Fran as she read the *Bitter Blockers* text. Fran only indicated attention to BB2 after reading the sixth paragraph, one of the three complementary instances in this text. Fran did not indicate attention to either BB1 or BB2 around the fifth paragraph, which contains the other two instances in which the prose and graphics were instructionally complementary. While reading, Fran seemed to struggle with making sense of what she read and used the think-aloud moments to check whether or not she understood what she read. In this case Fran was again using much of her attention toward making sense of the prose:

> **How do bitter blockers work?** Scientists who study how people taste once thought that a // specific
>
> ~ I'm gonna forget where that is but I'm gonna say that is my hard word [referring to "specific" and a previous question interviewer asked with Cooking with Ovens text about words difficult to read]
>
> [reads]: specific place on the tongue detects each flavor.
>
> ~BB-TA6. I'm not thinking of anything.
>
> [reads]: For example, the back right part of your tongue might detect bitter. The front tip of your tongue might detect sour. However, scientists changed their models of how people taste. They now know how, that you can taste each flavor on any part of your tongue. [skips BB-TA7] Scientists also know that the tongue is covered with tiny pinkish-red "mounds" (called //
>
> ~ yeah I don't know that [referring to "papillae"] [laughs]
>
> [reads]: These mounds are where the taste buds are.
>
> ~BB-TA8: Yeah I don't know that word [referring to papillae].
>
> [reads]: Taste buds help to tell what flavor the food is. When you chew, the // saliva in your mouth (your spit) breaks food up into single molecules. That make up the food. The food molecules touch ~~the taste buds. The taste buds then send a~~ signal to your brain that tells what flavor the molecule tastes like.
>
> ~BB-TA10: OK, [pause – fixing fold of the paper]
>
> [continues reading]: When a bitter blocker molecule is in the food, it blocks the bitter-tasting molecules from the touching the bitter
>
> ~ What?
>
> [rereads]: When a bitter blocker molecule is in the food…

Note that in this case Fran also seemed to skip some of the phrases that were complementary with BB2. Also, as the prose in the *Bitter Blockers* text shifted from the real-world applicative ideas to the more scientific ideas (around paragraph three), Fran provided less information in her think-aloud comments. She usually stated phrases like, "I'm not thinking anything…" The decrease in content during Fran's think-aloud comments may also be an indication that either her effort was mainly toward making sense of what she was reading or that she was disengaged with the task. Either case may have led Fran to focus only on the prose and not on BB1 or BB2 in these instructionally complementary instances.

Dana, another struggling reader, also did not demonstrate much engagement with the *Bitter Blockers* text, and she neither demonstrated nor reported attention to the graphics in the three instructionally complementary instances in the Bitter Blocker text. In fact, as Dana read, she provided very little in her think-aloud comments except that she was not fully engaged with the task. Dana yawned during the task, and only had single words as her think-aloud comments, demonstrating she was not very engaged in the text and the task of reading the text. This disengagement may have been a result of Dana's struggle to comprehend the text. The instance below occurred as Dana read prose near the instructionally complementary instance for BB1:

> Um. [reads]: **How do bitter blockers work?** Scientists who study how people taste once // once thought that a ~~specific~~ specia-
>
> ~ I can't say it
>
> [reads]: specify place on the tongue detects each flavor.
>
> ~BB-TA6: Um, I'm still thinking of "bitter."
>
> [reads]: For example, the back right part of your tongue might detect bitter. The front tip of your tongue might detect sour. However, scientists changed their models // of how people taste. They now know that you can taste each flavor on any part of your tongue.
>
> ~BB-TA7: _[inaudible]_Bitter.
>
> [reads]: **How do bitter blockers wor-**
>
> ~ I just read that right? Oh yeah. [chuckles]
>
> [reads]: Scientists also know that the tongue is covered with tiny pinkish-red "mounds" (called ~~papillae~~ pap-il-a). These mounds are where the taste buds are.

BB-TA8. [yawns] [pause] I really... I don't know.

Me: You're not really what?

Dana: Like thinking right now. All I can think of is taste buds.

Dana did not indicate why she seemed to think only of *bitter* or *taste buds*. In the pre-reading task Dana did bring up the idea that people taste with their taste buds. She also was assessed as having average prior knowledge of tasting and taste buds. However, when asked about what the text might be about, and what might be interesting about the text, Dana also seemed fixated on *taste buds*, and talked about the image of the tongue in BB1. Possibly, as Dana struggled to read and understand the prose in the instructionally supportive instance, she only focused on the two pieces of the text which seemed to be important and of which she had some experience and knowledge.

In these instances, Dana and Fran did not seem engaged in making meaning with, and therefore did not access, the science ideas the prose communicates. In other words, Fran and Dana were not in a position to utilize the graphics with the prose to make sense of the science ideas in the text. Dana and Fran's experiences lead one to question how best to support struggling readers. For example, if the role of a graphic was to support struggling readers, then in the case of Dana and Fran, how might this occur, and what does it mean for a graphic to be "effective"? In the next chapter I continue a discussion about this question and other questions deriving from Dana and Fran's case.

To further complicate the case, I describe Layne's engagement in a different instructionally complementary instance. Layne is another example of a reader who showed signs of struggle. He seemed to show confusion and difficulty making sense of what he read. Dana and Fran seemed to struggle at the word level and struggled with making sense of the prose due to the difficulty of the text and their reading achievement. However, Layne's struggle appeared to stem from his (lack of) prior knowledge. Layne did not comprehend the texts; he had lower-average prior knowledge of molecules and low prior knowledge of microwaves and ovens. The following commentary shows Layne's reading and think-aloud comments as he demonstrated his focus on only the prose at the instances where paragraphs three and four and MW1 are instructionally complementary:

[reads]: The hot air in the oven then heats the food. Fast-moving molecules in the air

collide with the food molecules.

~MW-TA5. I thought that the... that the molecules and the air probably, they bump together and stay together and start doing that because there's probably a lot of heat and they don't have anywhere to go but to stick to each other.

[reads]: The collisions make the food molecules jiggle faster. So the food molecules get more energy from the hot air molecules surrounding the food, and the food gets hotter.

~MW-TA6. Ok. [pause] I thought that how can a food molecule get more energy from the hot air molecules because aren't molecules the same thing? Like food molecules or regular molecules, aren't they the same? … Well, probably they are.

Me: I can't answer that question. …

Layne: [reads]: You might have noticed that when you take pizza out of the oven too early, the inside of the pizza is still cold. It takes time for food to become warm all the way to the center. That is because in a regular oven, all of the food molecules don't move faster at once. The ones on the outside edges of the food start moving faster. Then the~~y~~ collide with the food molecules on the inside, making the inside food molecules move faster. [skips MW-TA7] It takes a long time because the food molecules are colliding one by one, from the edge~~s~~ of the food–

~Oh!

[rereads before MW-TA7 marker]: making the inside food molecules move faster.

~MW-TA7. I think that when the molecules move fast, that means that the food is heating up more.

In this case, Layne's idea of food and air molecules as the same thing seemed to hinder his understanding of how energy is transferred between different types of molecules. Layne also appeared either to interpret certain words incorrectly (e.g., "collision" as not only bumping but also "staying together" and "stick[ing] to each other") and/or bring in his own prior knowledge of molecules and heat (e.g., due to a lot of heat the molecules have "nowhere to go"). These actions possibly limited his understanding of the science ideas in and comprehension of this text. Layne was not struggling to read the words in the prose, but his confusion with the ideas in the text emerged as signs of struggle in the instructionally complementary instances involving MW1. I speculate that Layne would most likely have continued to struggle with his understanding of the science ideas in this instructionally complementary instance even if he used MW1. This continued struggle would have been due to MW1's limitation in not addressing the incorrect interpretations and prior knowledge that Layne used. For example, Layne could have continued to think *collide* meant to stick together, as MW1 only shows arrows from one molecule to the next. Also, neither the prose nor the graphic details that the collisions by the molecules are elastic.

In another instructionally complementary instance (this time paragraph five and BB1), Layne seemed to be making sense of the science ideas necessary to understand the explanation of taste buds. Yet in his think-aloud comment during the instructionally complementary opportunity for BB1, Layne stated, “I was thinking that what do– papilli-ae does… what do they do? … what do they do, and how do they relate to the taste buds?” Layne did not indicate attention, nor show navigation, to BB1. I again question whether BB1 could have helped answer Layne’s questions. Some of the ideas he was asking about were communicated in the graphic. BB1 does not show what papillae “do.” The graphic does show a relationship between the papillae and taste buds. However, this relationship is buried among other conceptual structures and difficult for any reader to access and extract.

The possibility that Layne could have gained information that may have helped him to answer his question about taste buds and papillae if he had used BB1 also exemplifies the second characteristic of students’ engagement with only the prose in the instructionally complementary instances. This characteristic was more common with the *Bitter Blockers* text and the instructionally complementary instances with BB2 (paragraphs five and six). In fact, 3 intermediate readers and 2 struggling readers engaged with the *Bitter Blockers* text in this way, as shown next by Walei.

Walei was one of the intermediate readers who comprehended the text with no signs of struggle or confusion. She also had high prior knowledge of molecules and average prior knowledge of tasting and taste buds. As Walei read during the instances instructionally complementary with BB2, she made the following comments:

> [reads]: Scientists also know that the tongue is covered with tiny pinkish-red “mounds” (called papillae). These mounds are where the taste buds are.
>
> ~ BB-TA8. I thought the taste buds *were* the mounds. But I guess I was…
>
> [reads]: Taste buds help to tell what flavor the food is. When you chew, the saliva in your mouth (your spit) breaks food up into single molecules that make up the food.
>
> ~ BB-TA9. I think that the molecules have different tastes in them and that’s what makes like the food taste how it tastes.

[reads]: The food molecules touch the taste buds. The taste buds then send a signal to your brain that tells what flavor the molecule tastes like.

~ BB-TA10. Hmm, not thinking about anything there.

[reads]: When a bitter blocker molecule is in the food, it blocks the bitter-tasting molecules from touching the bitter-detecting taste buds.

~ BB-TA11. I kind of wonder how they do that because like... are they like blocking the way your tongue/ works or something like that?

[reads]: The bitter-tasting molecules are still there. [continues to read; no comments at BB-TA12].

In this example Walei asked how the bitter blockers block the other molecules. She also proposed, in the form of a question, the idea that bitter blockers might block the mechanism of one's tongue. Walei neither demonstrated nor reported looking at BB2 in these instances. The use of BB2 might have helped her to answer the questions she asked and therefore to build on her understanding about the instructional ideas in the text. The type of engagement that Layne and Walei show in these instructionally complementary instances are what I consider "missed" opportunities. However, I suspect the (lack of) accessibility of the instructionally central ideas in the graphics may have been a major factor in why students "missed" the opportunity to use the graphics at complementary instances, especially with BB2. In contrast, for the some instances, such as MW2, other factors (such as a student bringing in incorrect prior knowledge, similar to the example with Walei) possibly interacted with students' engagement with the prose in ways that might have led to confusion and/or simply not using the graphic.

One of the possible reasons why some students did not use a graphic in instructionally complementary instances is the students' understanding of the prose to the extent that they might not have needed to use the graphics. In this study students who seemed to make sense of the prose did not always use the complementary graphic. This is the third characteristic of students who did not indicate attention to the graphics in instructionally complementary instances, as demonstrated by Sam. Sam was an atypical case. She was a proficient reader (and comprehended both texts) with average prior knowledge of molecules and low prior knowledge of tasting and taste buds. Yet Sam demonstrated attention to a graphic in *only one* of the six total instructionally complementary instances. (In comparison, all other proficient readers indicated attention to graphics in three or more of the instances). The following instance illustrates how a proficient reader might focus only on the prose when s/he might benefit from using both representations:

> [reads]: For example, the back right part of your tongue might detect bitter. The front tip of your tongue might detect sour. However, scientists changed their models of how people taste. They now know that you can taste each flavor on any part of your tongue.
>
> ~BB-TA7. So, um. So, [sighs] so I'm thinking there must be like maybe a mix of taste buds like all over the place, not just in one specific spot.
>
> [reads]: Scientists also know that the tongue is covered with tiny pinkish-red "mounds" (called papillae). These mounds are where the taste buds are.
>
> ~BB-TA8. So that kind of tells you again that they're like all over, because it's like all... [continues to read]…

In this case the graphic included the ideas Sam discussed in her think-aloud comments and provided information that could have further supported her proposed synthesis. Sam's latter think-aloud comment (BB-TA8) suggests Sam used the prose she read to support her initial idea about taste buds (BB-TA7).

Sam's low prior knowledge of tasting and taste buds, along with the ideas presented in the prose, may help explain why Sam focused on the idea of where taste buds are on the tongue. However Sam's think-aloud responses, along with the fact that she did comprehend the text, make it questionable whether she needed to look at the graphic to understand the ideas discussed in the prose. In other words, there may be situations in which the reader has accessed "enough" information to comprehend, even if the graphic with the prose would provide a more comprehensive understanding about the instructional ideas in the text.

Sam was also the only reader out of all 20 students who neither demonstrated nor reported attention to MW2 in the instructionally complementary instance. At this instance Sam seemed to use her knowledge of light reflecting and compare it with the way microwaves travel:

> Sam [reads]: When you turn on a microwave oven, a device in the oven makes microwaves. The microwaves reflect off the walls of the oven and move in the oven in all directions.
>
> ~MW-TA9. So kind of like light.
>
> [reads]: The microwaves also go through the food. As microwaves pass through the food,

they are absorbed by water molecules in the food. The microwaves make the water molecules move back and forth faster (they move back and forth about a million times a second!). All of the faster-moving water molecules in the food then collide with the rest of the food molecules.

~MW-TA11. Um, [pause] I don't really have anything to say about that.

[reads]: That makes *all* of the food molecules move faster. When the molecules in the food move faster, the food heats.

~MW-TA12. So I'm wondering if that's just because of like some sort of friction or just moving really fast.

Sam also brought up ideas that go beyond the text. For example, to answer an implicit question of what causes the food to heat, Sam related her prior knowledge of friction to information from the prose about molecules moving faster. In these cases Sam seemed to rely on her comprehension of the prose and her prior knowledge instead of using the graphic with the prose to help her make meaning of the text. Cases such as Sam's also suggest that for some students, utilizing only the prose may not hinder their comprehension, nor would they be "missing" information. These cases also reflect the use of graphics not as a supportive feature (readers such as Sam seem to not need support), but instead as a tool similar to reading strategies that readers can use to comprehend the instructional ideas in the text.

Summary: Students' Prose-Graphic Engagement Via Instructionally Complementary Instances

In the above section I described students' prose-graphic engagement in instructionally complementary instances. The description included the identification of relationships among frequency of attention to graphics in instructionally complementary instances, integrated reading achievement, and prior knowledge. Struggling readers tended not to use graphics as readily in these instances regardless of their prior knowledge, whereas the intermediate and proficient readers with *low* prior knowledge indicated attention to the graphics in most instructionally complementary opportunities.

I reported that most of the students who used the graphics in more than half of the instructionally complementary instances had commented about the complementary ideas in their think-aloud comments. I also identified characteristics of prose-graphic engagement displayed by the 11 students who used the graphics in half or fewer of the instances. Three characteristics emerged that describe these students' engagement with the prose when they did not indicate attention to graphics in the instructionally complementary instances: (1) signs of struggle, whether it be confusion or disengagement with the reading task; (2) "missed" opportunities in which students made comments and/or questions about the science information that the graphic (in most cases BB2) provided; and (3) signs of engagement with and comprehension of the prose with no evident need to use graphics for comprehension.

The next section is the third approach I used to characterize students' prose-graphic engagement – that is, by describing students' prose-graphic engagement and its relationship to limitations and affordances of the texts.

4. Describing Students' Prose-Graphic Engagement Via Limitations of the *Cooking With Ovens* Text and MW1

As I mentioned in the previous section, I characterized some instances in which students (primarily the intermediate readers) seemed to have "missed" opportunities to access instructionally complementary information from graphics. I also suggest that these "missed" opportunities may have been due to the poor accessibility of the graphics. Indeed the texts in this study – the prose and graphics – had limitations that could hinder a reader's access to the instructionally central ideas in each text. What these limitations were, and what students did in response to the limitations, is the focus of this section. I discuss this interaction with a perspective of the bi-directional nature of interpreting the multiple representations in a text (in this case, that readers can use the graphics to make sense of the prose, and use the prose to make sense of the graphics). As stated in Chapter 2, research tends to focus on graphics' effectiveness and the role of graphics as supporting (or hindering) students' sense-making of the prose. Yet in this study, the *other* direction of the prose-graphic relationship emerged as an integral element to students' understanding of instructional ideas in the *Cooking with Ovens* text. In fact, I found that ***failure to comprehend the prose may contribute to misinterpretation of the graphic, which, for struggling readers, may then lead to lack of full comprehension of the text.*** A student's misinterpretation of either the prose and/or the graphic may not necessarily occur because of his or her characteristics, but instead because of the text's characteristics. However, the *interaction* of text characteristics, students' engagement, and students' characteristics can all factor into a student's comprehension of a text.

This interaction was most prominent in the *Cooking with Ovens* text and MW1. I therefore focus this section on this text and graphic.

<u>Possible Avenues of Confusion Based on Text Analyses</u>

Recall in Chapter 5 that I identified multiple aspects of MW1 that could possibly promote confusion. For example, the intention of MW1 was to represent molecules (the small circles) and the transfer of movement between these molecules (the arrows) with respect to their placement in food (the large circles). However, the lack of labeling in MW1 makes it difficult for a reader to make the connection between the "molecules" and "food," and that lack of labeling may promote confusion. I also noted in Chapter 5 that the elements in the graphic may suggest to the reader that symbols represent something that is communicated in the prose and/or captions – and that this may help or hinder students' comprehension depending on whether the interpretation is structurally and scientifically correct. I also stated that to interpret the graphic symbols this way was an example of how a reader must take information from other sources within the graphic itself as well as within the prose to make coherent meaning out of the graphic.

I also discussed possible difficulty in students' meaning making and understanding of MW1 because of lack of direction regarding interpretation of the colors in MW1. What the colors mean for the little circles with respect to the big circle that the little ones overlay does not follow any pattern. It is up to the reader to make a determination regarding what the colors represent. Also, the color conventions of the top and bottom images in MW1 are not consistent; the big circle in the top image and the circle in the bottom image are similar in size and similar with the use of color gradients, yet the colors are different. The colors are different because they represent different entities (e.g., faster-to-slower movement versus hot-to-cold temperature). However a reader might misinterpret the color gradients to represent the same entity, or question why they are different colors.

Multiple Avenues of Misinterpretation

Haiden, Dana, Kris and Quinn show the multiple avenues of misinterpretation that occurred due to both the limitations of MW1 and the complexity needed to integrate multiple forms of representation.

Haiden's case is the first example of ways some students tended to misinterpret the *Cooking with Ovens* text. Haiden was a struggling reader who did not comprehend the text. She had lower-average prior knowledge of molecules and low prior knowledge of microwaves and ovens. The transcript below is the first of Haiden's responses to the pre-reading prior knowledge questions about what molecules are and where they are. It shows some of Haiden's initial ideas before she read the texts.

Haiden first suggested the following ideas before reading the *Bitter Blockers* text (the first text she read).

> Me: Tell me about molecules
>
> Haiden: Well, they're like the mothballs that Mrs. Pippy showed us yesterday. I think there's like, in one mothball there's like things that are moving inside of it maybe. Or like in a liquid there's, um, like, say, orange pop there's a lot of molecules in it, where it's fizzy or something.
>
> Me: So you mentioned mothballs maybe in that there's moving inside mothballs. Is it molecules?
>
> Haiden: Yeah, I think they're molecules because ok, say if you had a microscope or something where you could look down on it, there's like little bitty things that are inside of it, like a disinfectant or something, where it is... like it's… like it's moving constantly but you can't see it unless you're looking in a microscope really closely.
>
> Me: Ok. So you mentioned that maybe it's in liquid. I was wondering where are molecules? You mentioned in liquid and in mothballs. I was wondering generally where are mothballs? I mean [laughs] where are molecules?
>
> Haiden: Well, I really think like molecules are like around the room.
>
> Me: Around the room?
>
> Haiden: Where like... like where you see... like in the air where you see a lot of dust coming down. It would be something like that.

It was clear that Haiden had limited knowledge of molecules. She verbalized molecules as moving, and the small size of molecules, yet held a particulate view in which she equated molecules with little specks of dust in the air and the fizz in soda. Haiden then provided the following ideas before reading the *Cooking with Ovens* text (the second text she read):

> Me: So I asked you about molecules and you said that they're in mothballs or maybe liquid, like orange pop. And that sometimes you see them when you see dust, like coming down, I think you said. When I asked you, "Where are molecules?" You said, "They're around the room." So I'm wondering if there's anything you want to add or change about what molecules are, or telling me about molecules?
>
> Haiden: Well, there's two– I guess there's two different molecules. There's a food molecule and another one that I don't know. And that, it um, the molecules are around the room and they are still dust where it comes down.

After reading the *Bitter Blockers* text and before reading the *Cooking with Ovens* text, Haiden still held the particulate ideas, though she added to her description of molecules, stating that there is more than one type of molecules. (This addition is most likely due to having read the Bitter Blocker text.)

Although Haiden indicated little attention to the graphics in the instructionally complementary instances, she did report engagement with MW1 around the complementary instance in paragraph three. The following are Haiden's think-aloud comments while reading the prose around this instance. Haiden's think-aloud comments first focused on the difficulty of reading and understanding the word "collision."

> Haiden [reads]: Regular ovens use hot air to heat food. When you turn on a regular oven, you can sometimes see ~~coils~~ coys in the oven get red-hot. The hot ~~coils~~ coys warm the air around them. The air warms up as the molecules in the air move around faster. [skips MW-TA4] The hot air in the oven then heats the food. Fast-moving molecules in the air collide with the food molecules. [Skips MW-TA5]
>
> Me: So you haven't been telling me what you're thinking. So tell me what you're thinking.
>
> Haiden: I'm wondering what is this word. It starts with a "c"… this word, right here <points to "collisions" in Paragraph 3>.

Haiden then misinterpreted the text when commenting on where molecules are, stating as a question that molecules are in a microwave. Yet the prose Haiden read dealt with a conventional oven.

> [reads]: The ~~collisions~~ colisins make the food molecules jiggle faster. So the food molecules get more energy from the hot air molecules surrounding the food, and the food gets hotter.
>
> ~MW-TA6. So there's molecules in the microwave?

Haiden's engagement with the text in this way shows her confusion about molecules. Haiden reported attention to the graphic in this instance, which suggests that she may have been strategic in using the graphic in order to build on and make sense of the ideas she read. Yet even if Haiden attended to the graphic during the instructionally complementary instance, she was not obtaining the instructional information needed to fully make sense of the text. Instead, Haiden's confusion about "molecules in a microwave" emerged. Multiple factors may have caused this confusion, including misunderstanding the prose and, as identified earlier as a possible source of confusion, the lack of labeling in MW1.

Haiden's confusion persisted after reading. When asked to describe the graphic and its goal, she discussed the idea of molecules in a microwave.

> Me: <points to MW1> Tell me a little about this.
>
> Haiden: Well, I don't really know like about this part <points to MW1 bottom image>, but I think I know about this one <points to MW1 top image> because the white, red, yellow, green and blue are the molecules moving around like, I guess it's a microwave, moving around.
>
> Me: Ok. What do think is the goal of this <points to MW1> diagram?
>
> Haiden: Well, I don't know what the goal is. It's not showing really much. Well it's showing like the molecules moving around in a microwave.

Haiden's responses show that she was not confused about the entire graphic, as she correctly interpreted the small multicolored circles as molecules. Later in the interview Haiden even correctly interpreted the different colors of each little circle to represent *different* molecules (which relates to her added knowledge of molecules after reading the Bitter Blocker text). Yet the large circle was to represent a piece of food, not a microwave.

Haiden's prior knowledge, her misinterpretations of the prose and graphics, and her difficulty comprehending the text, coupled with the affordances of the prose and MW1, could be considered to have created a domino effect: lack of comprehension of the prose leading to lack of full understanding of the graphic, together building toward lack of comprehension of the text as a whole.

Dana exemplifies another way that some students in this study tended to misinterpret or confuse information in the *Cooking with Ovens* text. Dana was reading about the relationship between molecules and cooking foods when, in her think-aloud, she commented that she did not know molecules "cook,"

> Dana [reads]: Regular ovens use hot air to heat food. When you turn on a regular oven, you can sometimes see coils in the oven get red-hot. The hot coils warm the air around them. The air warms up as the molecules in the air move around faster.
>
> ~MW-TA4. I didn't know that molecules cook. I didn't know that. It's freaky.

Dana's misinterpretation was similar to a common incorrect comment the students tended to make regarding molecules "heating up." In fact, 6 other readers seemed to misunderstand the phrase, "hot air molecules" as meaning "hot molecules." This phrase is in the third paragraph in the sentence, "So the food molecules get more energy from the *hot air molecules* surrounding the food, and the food gets hotter." The students seemed to interpret the phrase as *molecules which are hot in temperature* instead of the intended meaning of *molecules that make up hot air*. In fact, the third paragraph and parts of other paragraphs contain many phrases which could potentially lead to confusion. For example, *hot air in oven*, *fast moving molecules in the air*, *food molecules*, *hot air molecules*, and *food gets hotter* are all phrases in the paragraph that could prove difficult to tease out and make meaning from, especially for readers with little prior knowledge and/or lower reading achievement.

The inclusion of different colored molecules in MW1 may also have supported students' misinterpretation of the prose if the students interpreted different colors to mean different temperatures. As mentioned earlier, the color differences used in the bottom part of the graphic does refer to temperature, but the color differences in molecules in the top image of MW1 is intended to show the different *speeds* of the molecules.

Kris was one of the readers who misinterpreted "hot air molecules" as meaning "hot molecules." Kris was a proficient reader with lower-average prior knowledge of molecules and low prior knowledge of microwaves and ovens. His misinterpretation of "hot air molecules" is evident first in his think-aloud comments:

> [reads]: The hot air in the oven then heats the food. Fast-moving molecules in the air collide with the food molecules.
>
> Kris ~MW-TA5. Um... like... um, like also the fast-moving molecules in the air collide with the food molecules. Like I don't know if the food molecules are getting heated up with the fast-moving molecules that when they got heated up, or... it's kind of...

[reads]: The collisions make the food molecules jiggle faster. So the food molecules get more energy from the hot air molecules surrounding the food, and the food gets hotter.

Kris ~MW-TA6. So yeah like when the food molecules get more energy from the hot air molecules, they kind of like get more hot and they move faster and so like the food kind of stays warm. Yeah. [pause]

Kris also expressed confusion about MW1. At first he did not seem to understand that the "little circles" represented molecules. Then, as Kris continued to explain, his confusion about MW1's color conventions also began to emerge:

Me: Is there anything in the diagrams that didn't make sense to you, that was confusing?

Kris: Um, yeah. I kind of really didn't get like what these little circles meant <points to MW1; top image>, like if it meant like how it got warmer, or how it got colder. I kind of really didn't get that.

Me: So what did you do to try and make sense of that?

Kris: I was just trying to think if it was right, and I was trying to think to myself if it got hotter and then it got colder as it was going through the middle <points to MW1; top image, finger moving in and out of large circle>, or it got colder as it was going to the outside, and then like... And once I looked at this <points to MW1; bottom image>, the outside, how it got warmer, so I thought that this <points to MW1; top image at border of large circle> was warm and then it got colder as it went to the center. So it was kind of confusing, but I kind of figured it out.

Me: So in... well, did you use the passage to help you? What did(?) you read to help you understand?

Kris: Yeah, I kind of used mostly like this passage <points to page 1 and top of page 2>, like these two passages.

Me: So this? What paragraphs?

Kris: It helped me the most probably, the <points to paragraph 4> third paragraph.

Me: This one <points to paragraph 4>?

Kris: Yeah. That kind of helped me out more because it told me what happened, like if something wasn't cooked– done and like if when the outside got warmer and the inside didn't really get warmer and then the food molecules collided one by one. So that it took a while.

Kris's use of the word "it" makes it difficult to ascertain if his misinterpretation of "hot molecules" persisted. Kris's misinterpretation of the third paragraph (and the relationship of hot/cold molecules) possibly contributed to his confusion concerning MW1. He did report that the paragraph 4 helped him make sense of the graphic. Kris' comprehension of paragraph may have helped in his understanding of the color conventions, which in turn may have helped him with making more sense of the molecules.

Kris again expressed confusion about the colors later in the interview when he described how he would help other readers:

> Me: Ok. So say you had to help someone in your science class to read and understand this passage. In what ways would you help that person?
>
> Kris: I would either... if they asked about the diagrams or the passages or anything, like if they asked me about the diagram <points to MW1>, I'd be like... I'd ask them like... because like the outside gets warmer and so <points to MW1; top image> I'd say like as the white goes down, is it the colors? Well, how to put it– like… as the white– that means it's hot. And then it's getting cold as you go to the center. So then I'd show them where that said that in this passage <points to paragraphs 3 and 4>, and stuff like that…. [student continues to describe how he would help person with MW2].

Kris's comments suggest that the color conventions in MW1 seemed to provoke confusion mostly because the range of colors in the top image, going from outside to inside, differs from the range of colors in the bottom image. This difference was due to the colors representing different ideas. The colors in the top image were intended to represent different speeds of molecules, versus the colors in the bottom image, which represented varied temperatures. I did not predict this confusion in Chapter 5, although I did identify that confusion about the colors of the molecules may occur due to multiple reasons (e.g., lack of a patterns regarding the differences in color in the top image; lack of specific labeling and the student's need to infer meanings based on captions and student interpretations of the small circles). Kris's comment shows that another factor in a reader's confusion may also be due to the inconsistent meanings of the color gradients even within MW1 (i.e., between the top and bottom images).

Quinn was another reader who was confused regarding the different meanings of MW1's colors. Quinn did not demonstrate misinterpretation of the "hot molecules," but he did show how he worked through the prose to understand the graphic. As he reported in conversation/in the interview/in the transcript below, Quinn thought maybe different colors represented heat, and then, after reading more prose, he successfully identified the different colors as different speeds.

> [reads]: The hot air in the oven then heats the food. Fast-moving molecules in the air collide with the food molecules.
>
> ~MW-TA5. So I'm thinking... I'm sort of picturing a car crash. I don't know why, I just

was. Then I was looking at the diagram and it looks like it's changing color to show heat, but I'm not sure yet.

[reads; skipped, "The collisions make the food molecules jiggle faster. So the food molecules get more energy from the hot air molecules surrounding the food, and the food gets hotter." And skips MW-TA6]: You might have noticed that when you take pizza out of the oven too early, the inside of the pizza is still cold. It takes time for food to become warm all the way to the center. That is because in a regular oven, all of the food molecules don't move faster at once. The ones on the outside edges of the food start moving faster. Then they collide with the food molecules on the inside, making the inside food molecules move faster.

~MW-TA7. So I'm kind of picturing everything sort of melting.

[reads]: It takes a long time because the food molecules are colliding one by one, from the edges of the food to its center.

[reads caption from MW1; bottom graphic]: 'Overheating can occur on the outside.' 'Three hundred and fifty degrees Celsius on the outer edge ring' and 'two hundred degrees Celsius at the center.'

~ So that diagram is showing it's hotter on the outside than it is on the inside.

[reads caption from MW1; top image]: 'Increased movement, molecule by molecule from the outside.'

~ So I think the different colors are representing how quickly the molecules are moving.

After reading, Quinn expressed his confusion about the meanings of the various colors in MW1 while describing the graphic:

Me: Ok. How about you tell me a little about the diagrams? Let's start with this one <pointing to MW1>. Just tell me about this diagram.

Quinn: Um, well this one, I think it shows how the heating changes. And it used colors that you can sort of relate to. It builds up or cools down something. Like it starts red and goes to blue. If you didn't have that and it was talking about heat, I would guess that the red would be hotter than the blue. And then, [reads from diagram] "Increased movement, molecule by molecule, from the outside," I didn't really understand that. I noticed that it changes color and I was wondering if the colors meant it was at a different heat or if it was just so you saw it.

Quinn again brought up the colors in MW1 when discussing his interest in the graphics. Quinn hinted at his initial confusion, and eventual understanding, of the representation after reading the prose and captions, that "it all made sense after reading what it said."

Me: And what parts of this did you like?

Quinn: I liked how the colors built up to something, like on a map. It all made sense after reading what it said.

Quinn also attributed his understanding of the graphic to the prose when he responded to another question that asked how the prose might have helped him understand the diagrams:

Me: So what ways did the information from these diagrams help you to understand what you were reading?

Quinn: Because they connected to the text. Like this <points to MW1; bottom image>, for example, connected here <points to bottom of paragraph 4>. And this <points to MW1; top image> connected here, here too <points to paragraph 4>. And so they reinforced the reading– what the text was about.

…[later in interview]…

Me: Ok. And what ways did the information that you read in the passage help you to understand these diagrams?

Quinn: They connected them? Like I would have no clue what that <points to the top image of MW1> meant if I didn't read some of the paragraphs because it just wouldn't make sense to me because, [reads from diagram] "Increased movement, molecule by molecule from the outside," but once you read the whole article, you then know what it's about.

Quinn's comments clearly show that the colors in the graphic could only be correctly interpreted by reading the prose. Also, through his responses, Quinn demonstrated his knowledge by using the prose to help him interpret the graphic.

In Quinn's case, as a proficient reader (with high prior knowledge of molecules, microwaves, and ovens) he was able to comprehend the prose and work towards making sense of MW1. However, the ways Haiden, Dana, Kris and Quinn responded to the difficulty and limitations of the prose and MW1 in this instructionally complementary instance suggest that a reader who either (a) cannot comprehend the prose and/or (b) does not know to use the prose would have to rely on his or her prior topic and representational knowledge and any (mis)interpretation of the information (from the prose and/or graphic) to make sense of the text.

These cases also show different facets of students' meta-representational competence. Haiden, in correctly interpreting the little circles of MW1 as molecules (and the different colors as representing different molecules), demonstrated use of the sign systems for molecules. Just as Haiden's prior knowledge about molecules developed as she read the texts, her awareness of the meanings of MW1's symbols may have also been developed by her reading of the texts.

In the context of reading, however, Haiden was unable to utilize the prose or graphic to reduce confusion. Kris and Sam together demonstrated their use of the prose to help them (and, as Kris explains, to help other classmates) to make sense of the graphic. This demonstration reveals a type of meta-representational competence that is only found in *reading* science texts – that is, the integrative and bidirectional roles of prose and graphics such that each representation can be used to help support understanding of the other representation, and the text as a whole.

Summary: Students' Prose-Graphic Engagement Via Limitations of the Texts

In this section I described one phenomenon that occurred due to student and textual characteristics. Students showed how misinterpretations of or failure to comprehend the prose may lead to misinterpretation of and/or confusion about the graphic. The misinterpretations and confusion of struggling readers and/or readers with low prior knowledge may contribute to lack of full comprehension of the text. This outcome of misinterpreting the prose shows that in some cases students' understanding and interpretations of the prose, coupled with the affordances of and difficulty in accessing information from the prose and graphics, can be major factors in their understanding and interpretations of the graphics and the text over all. The cases showing such relationships also show various facets of meta-representational competence that the students demonstrated as they read and made sense of the text. I discuss students' meta-representational competence more in the next chapter.

In the next section I focus on features of graphics that are not only apparent in students' comments as a factor affecting students' interests in and understanding of the texts, but also integral to students' prose-graphics engagement.

5. Describing Students' Prose-Graphic Engagement Via Connective Features

To my knowledge research has yet to focus on connective features embedded in the graphics of science texts.[24] This section not only recognizes such features, but also emphasizes connective features within graphics as an integral element in students' prose-graphic engagement. In fact, ***students' prose-graphic engagement involved a prominent display of students' use of and awareness of connective features. Students also placed importance on connective features to make sense of the prose, to make meaning of the text, and to make the text meaningful.*** The students' orientations about connective features provide more insight about their engagement with graphics. The prominence of data in this study concerning students' display of using connective features also situates these features as both students' strategic use of, and their meta-representational competence in, using prose *and* graphics together.

As discussed in Chapter 5, the graphics in this study use an intricate combination of features to communicate information. In that chapter I also identified potentially interesting components of the prose and graphics. My identification of many elements as potentially interesting was due to their contextualization – that is, any way the element reflected practical or actual experience, and especially any possible relation to students' experiences. However, a feature that is contextual may not be connective. In order to be connective, these features must also relate to the science ideas that explain the everyday experienced situations.

Recall in Chapter 5 that I described how MW1 portrays no identifiable, real-world object. It also entails no degree of realism and instead incorporates abstract signs and symbols to represent entities in the world. On the other hand, MW2 portrays a microwave, turkeys, and even circumstances that added to the contextual nature of the

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[24] What I call connective features have been, in literature, called contextualization and/or contextual elements (see <u>Chapter 2</u> and, in this chapter, <u>Step 5: Analysis of Texts</u>). Connective features in graphics are realistic depictions (also called real-world examples) that encompass two types of "connections": (1) The first involves a connection with students' lives (i.e., examples that students most likely have directly or indirectly experienced). Note that with this connection, the reader is the one who will in the end make connections among his or her experiences with the text features, his or her self, and his or her experiences with the world. (2) The second entails intertextual links (i.e., connections between real situations and science ideas surrounding the situations, and relationships between the real everyday and the abstract scientific).

turkeys (e.g., lines to depict a plate and garnish below the turkey). I also identified and described the inclusion and lack of connective features in BB1 and BB2 respectively. The "person with tongue" image (a real-world and experienced object) and the image of the layers of the tongue (in which the layers provide a degree of realism) are considered connective features of BB1. BB2 lacks connective features. It contains no person or real-world images, nor does it have images with any degree of realism. In my analysis of the texts' interestingness (see Chapter 3) I applied some of those connective features as possible avenues to support student interest. Tables 6.7 and 6.8 summarize the features that I noted as potentially interesting due to the connective nature of each feature.

Table 6.7. Connective Features in Cooking with Ovens Text

Placement in Text	**Feature (Description or Quoted Prose)**
In Prose (Paragraph Number)	
1; 4; 7	Pizza; hot chocolate as foods heat
2	"see coils in the oven get red hot"
3	"hot air in the oven"
5	"…when you take pizza out of the oven too early, the inside of the pizza is still cold"
6	"They [molecules] move back and forth about a *million times a second*!"
In Graphic	
MW1	Similarity of signs/symbols to real-world or experienced objects: Circles resemble pizza, earth, bubbles
MW2	Turkeys and circumstances around turkey (e.g. plate and garnish)
MW2	Microwave oven and its features (e.g. buttons; window)
MW2	Similarity of "stirrer" with that of a fan

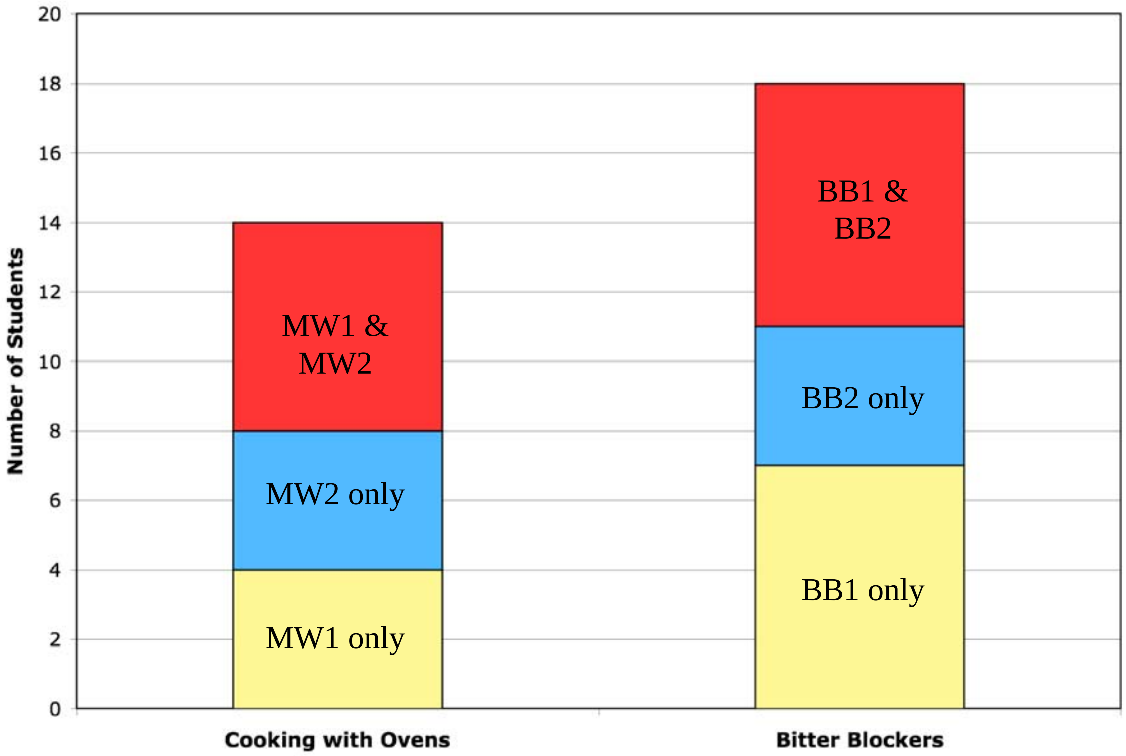
Table 6.8. Connective Features in Bitter Blockers Text

Placement in Text	Feature (Description or Quoted Prose)
In Prose (Paragraph Number)	
1	"When people taste something sour, they often make funny faces"
2	List of items that may be bitter; what reader may or may not like
2	"Coffee also has a bitter flavor, which is why some people add milk, cream or sugar…"
4	" specific place on tongue detects each flavor"
5	Spit
7	"People have tasted grapefruit juice…nasty…tangy but not bad…"
In Graphic	
BB1	Picture face with tongue
BB1	Middle, zoom-in image: layers look real, but can look like many different things, "lasagna" (a student also mentioned a forest)
BB2	Similarity of signs/symbols to real-world or experienced objects: Receptor with molecules "like a basketball" (or similar type of game)

Using and Valuing Connective Features

Students brought up connective features throughout all parts of the interview. In fact, all 20 students made at least one statement that related to the appearance and/or lack of connective features in the graphics. Figure 6.13 shows the number of students, per text, that brought up and/or discussed connective features during the reading and post-reading tasks. Each column shows the number of students who mentioned connective features in relation to one or both graphics in that text. For example, of the 14 total students who mentioned connective features for the *Cooking with Ovens* text, 6 readers did so with respect to both graphics, 4 others did so with respect to only MW1, and 4 others did so with respect to only MW2. Figure 6.13 shows that connective features prominently were mentioned by students with both texts and each graphic.

Figure 6.13. **Number of Students who Mentioned Connective Features by Text**



Connective features emerged as prominent factors around three general topics: (1) understanding of the graphics and texts (i.e., students' understanding and ways to support a reader's understandings), (2) the graphics' usefulness (i.e., the ways they found the graphics useful or not), and (3) interest in the graphics and texts (i.e., students' descriptions of their interests and ways to support a reader's interests). ***The consistent inclusion of connective features when students discussed the topics of understanding, usefulness and interest shows that students valued connective features as a means of making sense of, and supporting understanding of, the prose and entire text.*** These three topics are embedded throughout this section as I describe students' use of, and the importance students placed on, connective features.

Students Used Connective Features to Connect

One theoretically expected way students engaged with graphics that contained connective features (MW2 and BB1) was by connecting the features to themselves, their experiences, and their interests. Indeed students readily demonstrated using connective features to connect the science information to themselves. For example, Fran and Layne demonstrated their use of the tongue's connective role in BB1. Fran pointed to her own tongue when describing the graphic BB1:

> Me: Just tell me a little about this <pointing to BB1>.
>
> Fran: *That the tongue, like right here <pointing to own mouth> in your mouth*, [italics added] is pointing and there's taste buds and all kinds of words that I can't even spell. And then it points there <points to BB1; right image>.

And Layne's reason for BB1 being most helpful to his reading was due to the graphic's connection with the body:

> Layne: That one <points to BB1- finger is on the tongue>.
>
> Me: That one. You liked it the most?
>
> Layne: No, it helped me.
>
> Me: It helped you the most.
>
> Layne: Yeah.
>
> Me: Ok, so why was it most helpful?
>
> Layne: Because *it showed you everything. It showed the tongue and stuff that... about your body*. [italics added]

Students also made connections between their personal experiences and interests and the connective features. For example, Walei's verbal description of MW2, along with her gestures, shows a possible connection to her experiences with microwave ovens as well as heating water:

> Walei: Well, it kind of shows you how they like, um, like when... it kind of looks like when you press the buttons [puts finger on buttons of microwave oven (MW2) as if pressing], it like sends a signal to that thing, and this thing knows how long to keep the microwaves going, I guess. And down here <points to MW2; towards captions and small turkeys>, it kind of shows you how like the water molecules, when you just put it in there <points to MW2; left-most little turkey near bottom>, it's not even heated up at all. And then once it like keeps going the water gets hotter and starts to boil, and then when you take it out that's why it's hot, I guess. Yeah.

Later in the interview Walei also suggested the inclusion of more contextual information that reflecting practical use of a microwave oven as a way to change the graphic's level of interestingness:

> Me: O.K. What type of graphic would you put there to get someone to be interested in what they are reading?
>
> Walei: I would probably just make it colored. And I would also make it so that um, it like you could... I would make it colored and I would like put actually how it really does work, like all how when you type in a number <points to MW2; microwave image> you can see on there and how it recognizes the number and makes it go for a certain amount of time that you put on.

This suggestion demonstrates how Walei was connecting her experiences with microwave ovens and the contextual features of MW2.

As another example, one of Macy's interests in MW2 was the "turkey parts." When asked why he liked the turkey parts, Macy's response was simply, "Hmmm, because I like turkey." In this case, Macy's engagement with MW2 was due to, among other aspects, his previous experiences with (and liking of) turkey. In Macy's case, the feature matched positive experiences, promoting engagement. Yet as I discuss later, the application of students' experiences and interests to the connective features can promote either positive or negative interactions.

Students Placed Importance on Connective Features

Demonstrating how MW2 and BB1 Helped to Understand the Texts: Students showed they valued connective features in MW2 and BB1 when describing how the graphics helped them make sense of the texts. Note in Layne's response above that BB1 *helped the most* as he read and made sense of the text. Layne's response suggests his ideas of what was helpful to him involved the connective role of the tongue in BB1. Other students also demonstrated that they valued connective features as they described how the graphics supported their understandings of the text. For example, when I asked Haiden about the ways the graphics may have helped her to understand what she was reading, she answered by discussing how BB1 was helpful to her in obtaining some understanding of the text before reading:

> Me: Ok. So in what ways did the information from these diagrams help you to understand what you were reading?
>
> Haiden: [pause] Well… the pictures?
>
> Me: Hmhm.

> Haiden: …[It] Was helping a little before I read the text. This picture <points to BB1> was helpful because before I read the text um, it was showing a picture of a tongue. So I'm like, ok it's about the tongue. So I was thinking it was about tasting something. So…

In this case Haiden focused on the tongue in determining that the text might be about tasting. In doing so Haiden most likely thought about the pre-reading questions as well; she did bring up the placement of taste buds on the tongue when I asked her to tell me about taste buds during the pre-reading task.

As a unique case, Haiden even connected a connective feature of the prose in the *Cooking with Ovens* text (pizza) with the oven in MW2 to help her make sense of what she was reading:

> Me: When you were reading, were there any times that you took information from the diagram and matched it with what you were reading?
>
> Haiden: Yeah.
>
> Me: Yeah? Can you tell me about it?
>
> Haiden: Well, um, when it said the first paragraph I think, yeah. The first paragraph it was talking about eating pizza. So I was taking the microwave picture and fitting it in and trying to see what, where they're like talking about, so.

Haiden, in discussing how she used the connective features to "help" her, showed how even struggling readers may value connective features as helpful to their understanding of the text.

Vaan showed another way students valued the graphics' connective features as useful to their understanding of the texts. Vann identified the connective features of MW2 as "more information" that helps to communicate how a microwave works:

> Me: So what makes this <points to MW2> interesting?
>
> Vaan: There's a lot of information. It's got how <points to MW2; microwave oven image> the antenna and magnetron and waveguide and stirrer and microwaves... I think it just has a lot more information about how this <points to MW2; microwave oven image> works. This <points to MW1> doesn't really tell you how it works as well as this <points to MW2> one.

Here Vaan's identification of MW2 as having "more information" because it has connective features is also what makes Vaan more *interested* in the graphic than MW1. In this case Vaan was demonstrating the importance he placed on the connective features that ultimately supported his interest in MW2.

The prominence of connective features in students' responses about their understanding and interest also aligns with recent research on learning science. Rivet & Krajcik (2008) reported a correlation among students' "engagement" with connective features (which the authors call the features "contextual features") within instruction, and their gains on a pre-to-post test assessment. The authors suggested two theories as possible reasons why this correlation occurred. First, the contextual features in instruction may have supported students' development of a cognitive framework to connect the science ideas. Second, the features motivated and engaged students in the task, thereby supporting learning. The data I show do not include the outcome of learning. However, the data provide evidence that students engaged with the connective features in graphics in multiple ways, two of which may entail students building the science-world connections into their schema and/or becoming motivated by the features to engage with the text (and possibly to access the science information).

Incorporating Connective Features to MW1 and BB2: Students' prose-graphic engagement also involved applying connections to those graphics that lacked connective features (MW1 and BB2). Many students included, or proposed inclusion of, connective features to MW1 as a way to support understanding of the *Cooking with Ovens* text. For example, Haiden demonstrated that she needed a visual of a regular, conventional oven to help her understand prose about that oven:

> Me: So when this was confusing to you, this paragraph you said, was there anything in the diagrams that might have helped you better understand this paragraph?
>
> Haiden: Well, I looked at the microwave cooking diagram and I was putting in like, if that was the regular oven and just putting it in this place showing how the coils heats up the food faster than the regular oven, and then, that's it.

Alternatively, Jessie, when asked how he might change the graphic to support understanding of the text, proposed making an "oven" similar to MW2:

> Me: Ok. I'm curious if there would be any other types of pictures or graphics that you would put here to help someone understand what they are reading?
>
> Jessie: I don't know about that <points to MW2>, but for this <points to MW1> one, I would like put how some ovens look like inside, like basically this one <points to MW2>.

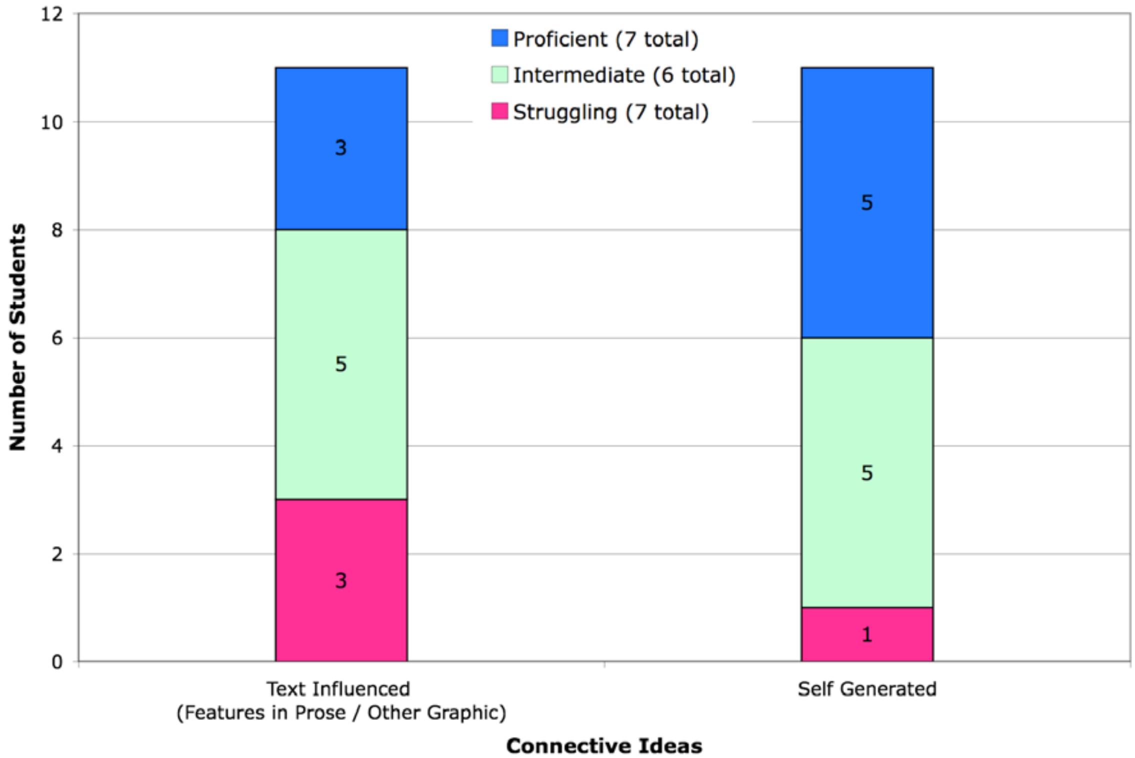
In Jessie's case, he believes addition of connective features (illustrating "how some ovens look inside") would help readers to understand what they were reading. Jessie's comment also illustrates his inclination to make the two *Cooking with Ovens* graphics structurally equivalent. Only one other reader showed awareness of the structural comparison between a regular oven and microwave oven. In asking Rene how the graphics related to the prose, Rene said,

> Rene: … And… It actually only shows... I think it should show kind of like this <points to MW2> one. It only shows the food molecule <points to MW1> and I think it should show the whole oven, with the molecules bumping into there or something.

Rene's statement exemplifies an awareness that the graphics are not comparable and that they should be. Rene's comment may also have been due to his knowledge of the structure of the text, as he provided the suggestion as a response to a question about how the graphics relate to the prose.

As the examples by Haiden, Jessie and Rene show, many students' reactions to the *lack* of connective features in MW1 were to apply such features to the graphic. This reaction also occurred with BB2. By doing so, ***students either applied connective features already in the text, and/or introduced self-generated connections when engaging with graphics that lacked such features (BB2 and MW1)***. Figure 6.14 shows the number of students that incorporated a text-influenced and/or a student generated connective feature.

***Figure 6.14.* Text-Influenced Connective Features and/or Self-Generated Connections by Reading Achievement**



<u>*Text-influenced Connective Features:*</u> Students' incorporation of connective features in graphics that lack them was most noticeable when students applied the meanings they made from the prose (or in one case, the meaning made with the other graphic's connective features) to the graphics. Eleven students applied such connective features to graphics that lacked them.

The text-influenced ideas included applying a pizza, oven, turkey, or a general "food" as text-influenced connective features to MW1. Jessie and Sam proposed such additions when asked how they might change the graphic to support understanding of the text. Jessie proposed making an "oven" similar to MW2 (above), and Sam proposed using a pizza in the graphic – still utilizing the connection of the color conventions but doing so on the pizza image:

> Me: … What type of graphic would you put here to help someone understand what they're reading? Or how would you change these to help someone understand what they were reading?

> Sam: Well, this one [MW1; bottom image], since they're talking about the whole pizza thing, I might put a picture of an actual pizza, and then put like certain colors to show where it's hot and where it's not. That's pretty much all I'd change.

Sam and Jessie's proposals came about in response to the question of how to change graphics to support understanding.

Other students reported using the text-influenced connective features as they read and made sense of the text. For example, Xipil discussed using the idea of the pizza to help him make sense of the graphic:

> Me: Were there any ways that the information you read helped you to understand the diagram?
>
> Xipil: Well [for] this one <points to MW1> –
>
> Me: Hmhm.
>
> Xipil: Um, it's sort of the same thing that I've been saying again. Like with the pizza, it helped me understand what this <points to MW1> was explaining.

Xipil's comment also shows how students relied on both directions of the prose-graphic informational relationship. In this case, the use of connective features in the prose supported Xipil's interpretation and understanding of the graphic.

Students also demonstrated and/or provided similar types of suggestions when asked about BB2. The demonstrations and suggestions included adding or changing the graphic to show bitter foods, candy, and AMP (a specific bitter blocker introduced in the prose), as well as a general picture of food plus a head and brain, to the Bitter Blocker text. Garnet and Macy proposed text-influenced connective features of this nature as ways to change the graphics for interest and understanding. Garnet, when asked how she might change or add to BB2 to support interest, suggested the addition of graphics to show foods that are more and less bitter:

> Me: Ok. How about to get someone to be interested in the reading. What type of graphic would you put in this passage to get someone interested in what they're reading?
>
> Garnet: Maybe like a graph of the most bitter to the least bitter foods.
>
> Me: Is there anything else?
>
> Garnet: Maybe a pie chart that shows people's favorite bitter foods to people's least favorite bitter food.

This proposed graphic would closely relate to the first section of the prose, which describes different foods that have a bitter flavor. The examples of foods with bitter flavors were intentionally included as a connective feature within the prose to support students' interest in reading the text.

Macy also suggested adding graphics that relate to connective features of the prose, this time focusing on the last paragraph of the text, which describes a study of bitter blockers' effectiveness:

> Me: …Besides these graphics, what type of graphic would you put here to help someone understand what they were reading?
>
> Macy: Like if they read this <points to paragraphs 5 and 6> and they didn't understand, then I would help them look at this <points to BB2> diagram.
>
> Me: Ok. But what other... say if you could change these or if you could put another picture or diagram here to help someone understand, what would you do?
>
> Macy: Well, I would draw– well, to understand. This part <points to BB1> is for here <points to BB page 1>. And this <points to BB2 right image> part is for here <points to paragraph 6> and for mostly all of this <points to paragraphs 6 and 7>. But this part <points to paragraph 7>, I could like draw two diagrams of... with regular grape juice without sweet, and I can make the person say "nasty" and could draw another one with AMP. And I could show how they put it in and I could write the person saying "tangy." <When describing, placing fingers on empty space at bottom of BB page 2>

Neci also demonstrated the bi-directional nature of prose-graphic engagement and the importance of the text-influenced connective features as a factor in the bidirectional process. In this case, as he was expressing his interest in the text, Neci took a connective feature of the prose and applied it to the BB2 image:

> Me: Are there any other parts that made it [the text] interesting?
>
> Neci: The chocolate, vegetable and medicine part <points to paragraph 2> was kind of interesting… For instance, with grapefruit juice, I learned that it's because of bitter molecules that like go into <points to BB2 right image> taste buds and didn't really ________________.
>
> Me: What was that last part? I got kind of confused because you were talking about the grapefruit juice, and then you pointed over here <points to BB2 right image>.
>
> Neci: Yeah, like I'm assuming that this bitter molecule <points to BB2 right image> is from grapefruit juice <points to paragraph 3>. And if it like... it shows how the bitter-blocker works <points to BB2 right image>.

As mentioned earlier, most of these inclusions of the contextual features from the text occurred when probed for suggestions or ideas to change the graphics. However, Neci's comment is an example of those instances when students automatically applied the connective features (i.e., without probes) to help understand and make meaning of the graphics and entire text.

Self-Generated Connections: The above examples show how students connected the contextual features *in the prose* to guide their interpretation of, interest in, and/or ideas of usefulness of the graphics that lack connective features. In a similar manner students also incorporated *self-generated* connections: ideas students introduced that were not discussed in the prose, yet connected the graphic to students' experiences, interests and/or prior knowledge. Application of self-generated connections to graphics that lack connective features is an indication of students' inclinations and orientations regarding connective features, especially toward supporting their interest and understanding of the text.

Notice in Figure 6.14 that although the same number of students applied text influenced connective features versus self-generated connections, most of the students who applied self-generated connections were proficient and intermediate readers. This difference suggests that ***struggling readers may not as readily apply self-generated connections to graphics that lack connective features.*** The difference may also indicate that application of self-generated connections to graphics may be a strategy to make sense of the text in the same way that one would refer to prior knowledge to make sense of prose.

Both positive and negative outcomes seemed to occur when students applied self-generated connections. ***In some cases, students' self-generated connections related to the science ideas communicated by the graphic(s), and in doing so, seemed to support students' science comprehension.*** For example, Patel suggested the addition of a cross section of a person's head with an illustration of the process of molecules touching taste buds and information being sent to the brain as a way to change the graphics to support understanding of the *Bitter Blockers* text:

> Patel: Well, I'd probably get rid of this <points to BB1> because I don't think it needs to be there.

> Me: This whole thing?
>
> Patel: Just that <points to BB1; right image of a magnified taste bud>.
>
> Me: Just this <points to BB1; right image of a magnified taste bud>.
>
> Patel: Oh, one thing I'd probably add is kind of maybe show a kind of like a diagram of a head cut in half, where like it kind of shows how the molecules touch your taste buds and that sends a signal to your brain, maybe.

Patel's suggestion incorporates the same aspects that emerged with students focusing on connective features in graphics that have them. Her suggestion (the addition of a cross-section of a head) would have a connective role (and the head would possibly better connect the ideas to student's interests and experiences). Patel's suggestion would also possibly help students make sense of the text by communicating information in the text (i.e., the bitter blocker connecting to a taste bud). Patel's suggestion of showing how the taste buds send a signal to the brain is also information that goes beyond the text, but it is information about which many students asked.

Xipil also provided a student-generated connection for BB1 but did so as she explained her interest in the graphic, and without prompting:

> Me: Are there any parts specifically that you thought were interesting about either of these?
>
> Xipil: I think this <points to BB2> one– part of this one, because the bitter-blocker looks sort of like a molecule. So I guess it would be like two... I sort of related it to two magnets, like that side and that side it would bounce off.

In relating the way a bitter blocker works to a magnet and to her experiences and knowledge of how magnets work, Xipil brought in her own connective feature to make sense of BB2. Though not scientifically accurate, applying magnets to the graphic possibly helped her to visualize the way some molecules may attract and connect to, or repel from, taste buds. Also, by linking information in the graphic to her prior knowledge (e.g., something with which she is familiar), Xipil supported her interest in the graphic. In Xipil's case the interaction of her self-generated connective idea interacted with both the science ideas in the graphic and with her interests.

In other cases, students connected the graphics to an idea that did not relate to the science ideas in the text. In these cases, students' interests, disinterests, or possible confusion became apparent factors in their engagement with the graphics and texts.

Dana is an example of a reader whose engagement with the graphics and texts throughout the interview seemed to be driven by the connections she was able to make with the texts she read. For example, the connections Dana made with the *Cooking with Ovens* text supported her interest in the text. Earlier in the interview I asked if and why Dana was interested in the *Cooking with Ovens* text. Dana's interest was driven by her experiences in cooking foods:

> Me: Ok. So talk about this whole entire passage. How interested were you when you read the passage?
>
> Dana: Really interested.
>
> Me: Really interested?
>
> Dana: Yeah.
>
> … [later in interview]
>
> Me: Was there anything in the words in the paragraphs that you thought were interesting?
>
> Dana: That the outside of whatever you're cooking gets done faster. Then it takes a longer time to get the middle to heat up.
>
> Me: And why did you find that interesting? Why did you like that?
>
> Dana: Because I always cook and wonder why the edges always get done first and not the middle.

This focus on her experiences and curiosity in why the edges of foods are done before their center persisted through the interview. This focus was again noticeable as Dana described ways she found MW1 and MW2 useful:

> Dana: Well, they [the graphics] were useful because I can see what heats up first <points to MW1; top image> and then in the center and all that. This <points to MW1> one was useful because it shows how it heats up... not how it heats up, but where it heats up and degrees and all that.

This focus also persisted as Dana described her interest in MW1:

> Dana: Like um, the colors <points to MW1; bottom image>, like it shows like, what– at the outer edge, like when you read this <points to general prose on page 1], it tells like the end <points to MW1; bottom image> gets done first and then the middle, and it shows <points to MW1; bottom image> that first at the outer end and then the center.

Dana regarded the graphics as useful and interesting because they connected to her experience of cooking foods.

However as Dana showed in her engagement with BB1, sometimes the connections a student makes results in a negative reaction. In discussing her interest in the Bitter Blocker graphics, Dana compared the middle image of BB1to meatloaf, which is a food she dislikes.

Me: So what about the diagrams? How interested were you in looking at the diagrams?

Dana: Not really.

Me: No?

Dana: No.

Me: Were there any parts that you liked on the diagrams?

Dana: Well, first I used to like that <points to BB1; center image>, but I don't now.

Me: Why don't you now?

Dana: Because it looks like a piece of meatloaf. I don't like meatloaf.

Seeing the image in BB1 as a piece of meatloaf affected her disinterest in, and possible disengagement from, the graphics in the *Bitter Blockers* text.

Dana's self-generated connective idea was applied via an incorrect interpretation of the graphic. This connection did not relate to the text, but it still promoted disengagement. Similarly, applying connective ideas incorrectly, such as identifying images in the graphics as something students have experienced when the images were actually of something else, may confuse the students and further complicate their meaning making and comprehension process. For example, in talking about how useful he found the graphics, Casey expressed that to him, BB2 was not as useful as BB1. Then, when asked what makes BB2 useful, Casey expressed confusion about what the images in BB2 represent:

Me: So what made this <points to BB2> useful?

Casey: It sort of shows that it covered up the thing <points to BB2, right graphic>. At first, I didn't know that that was like a taste bud, so I didn't completely understand what it was showing. Then I noticed that it was a taste bud.

Me: When did you notice that it was a taste bud?

Casey: When I was looking at it for the other questions <points to paragraph 7, second to last line>. At first, I just sort of thought it was like a head or something. That's what I noticed.

Rene also reported the same misinterpretation with BB2, and suggested making the images "more realistic,"

> Rene: …Maybe I'd make the diagrams a little bit better because when I first looked at this <points to BB2 graphic>, it kind of looked like a person, like a head with like shoulders. Yeah, I'd probably just make it look more realistic than it does.

In Casey and Rene's case the misinterpretation was most likely due to the shape of the symbols used to represent a taste bud and bitter blocker, as well as possibly a quick glance at the graphic. If the author did not intend the connection, and if an incorrect interpretation occurs, then making such self-generated connections might increase difficulty and/or confusion in students' work at understanding the text. Fortunately, in these particular instances, the students seemed to realize their interpretations were not correct.

By applying text-influenced connective features and/or student-generated connections to the graphics that lacked such features, students showed their orientations toward connective features in the graphics as a factor in their reading and meaning making processes. Next I discuss how students also demonstrated awareness of the apparent connective features.

Awareness of a Graphic's Connective Features

Students demonstrated their awareness of connective features as a principal component in their reading and meaning making of science texts with graphics. For example, as I described earlier, students' *inclusion* of connective features to support interest, usefulness and/or understanding suggests students were aware that the features could be strategically used in such ways. ***Students also demonstrated their awareness of connective features by their recognition of some connective features' connective roles and by their critical assessment of the graphics.***

Recognizing Connective Features' Connective Roles

Students did not just recognize apparent connective features; they were also aware of the features' connective roles. This awareness was illuminated by students' comments about the tongue in BB1. In the case below, Vaan mentioned the diagrams when describing what parts of the *Bitter Blockers* text he found interesting. I probed further, asking Vaan what parts of the graphics were interesting to him, and he replied,

> Vaan: I liked these parts <points to BB1; middle (magnified) and right (taste bud) images>. Like they didn't just show this <points to BB1; middle (magnified) and right (taste bud) images>; they put a picture <points to BB1; left (tongue) image> to make sure you understand about the tongue, so you know it's the tongue.

Vaan's comment directly reflects the tongue image's connective role, specifying that it is present to provide a context for the other images in BB1.

Xipil also provided a critical assessment of BB1 that reflected her awareness of connective roles. Xipil, in providing ideas for changing graphics to support understanding and interest, suggested more *realistic* images would help:

> Me: Or how would you maybe change the graphics? Or what would you put there if you thought someone didn't understand this text? What do you think would help them understand the text?
>
> Xipil: I think that they could do a closer image of this <points to BB1; mid (magnified) image>, so that you could see more of it. And maybe, um, like a more detailed picture. Or just like a picture of not just the taste buds, but of the whole mouth.
>
> Me: And what would that do?
>
> Xipil: Well, not of the whole mouth, but like of the whole tongue. And like you could have...well, the question you asked before... you could add a diagram. I just thought of something. You could put like a picture of the tongue and like zoom in on the actual taste buds. Maybe not just like freehand drawings, but maybe just like a *real picture*. [italics added]

Xipil's comments show that students may think cartoon-looking images like those in BB1 are not enough to contextualize and to support understanding and interest – even when a connective feature such as a tongue is present in the graphic. Directly and indirectly, the students seemed to recognize the connective role a graphic (or feature in a graphic) can play.

<u>*Critical Assessment of the Graphics*</u>

Another indication of students' awareness of the connective features involves their assessment of the graphics and suggestions to change the graphics to support understanding. For example, some students suggested simplifying the graphics and taking away certain connective features. Blair, Rene and Jessie were the few students who seemed to think the connective features limited interest and understanding, and made suggestions accordingly.

Blair's critical assessment involved BB1. Blair suggested changing the BB1 graphic to make it simpler and to eliminate any real-world images:

> Blair: Well, I might like, um, well something that is always a little hard to see is having like it very detailed or something. Kind of like that <points to BB1; middle image> so that it's, um, darkened I guess, because it's black and white. So all the gray gets really dark and all the... So I would probably make simple pictures. Like this <points to BB1; right image, taste cell> isn't very complex, but– these <points to BB2; right image> aren't either, but like, that <points to BB1; middle image> one is kind of complex. Or like, make it bigger, or make it with different color so that they would show up next to each other better.
>
> Me: I'm curious... what kind of picture? If somebody didn't understand this, what kind of picture would you draw? You said you would draw a picture.
>
> Blair: Probably a very, very simple one. Like not the hard way... not even drawing the real look–- what it looks like, but like just drawing a basic, of it. Like, a food is a circle and… a square for the taste bud.

As Blair began to describe how she would change BB1, her suggestions involved improving the images' clarity. Blair also noticed the complexity and simplicity of the images in BB1, and suggested "mak[ing] simple pictures." When probed further about the pictures, Blair suggested using simple shapes to represent otherwise complex entities. These simple shapes would replace, and therefore solve, the problem of unclear details within the realistic images.

Rene's critical assessment involved MW2. Rene explained his confusion about parts of the microwave, and he suggested eliminating parts of the microwave oven as in the graphic to support interest in the graphic and text:

> Rene: Anything I would add...
>
> Me: ... or change.
>
> Rene: ... or change. I might just like take out this microwave <points to MW2; microwave oven> because they don't really need those buttons and stuff like that. Since you said they don't understand what they're reading, I don't really... I don't understand what's the magnetron and the antenna and the waveguide and the stirrer. They didn't explain that at all, so I'd probably take that out and just show like a turkey or piece of pizza or something.

In making this suggestion, Rene was one of few students who demonstrated awareness of the possible negative aspects of connective features. Rene suggested eliminating the connective features altogether. On the other hand, Jessie suggested separating the connective features (e.g., the oven and its parts) from the information described in the captions in order to support interest:

> Jessie: …And just a picture of a microwave <points to MW2>, like how they set it up, and then like tell them... and then another box, tell them about like since they read this <points to prose above and below MW2> one, they can just look on the picture and see like what this passage <gestures the entire prose> was talking about.

These students made clear the possibility of students' disengagement with and/or lack of understanding of the text because of the way connective features are embedded in the graphics. In fact, researchers have recognized that graphics can "seduce" readers' attention away from a text's major message (in this case, away from the science ideas) and potentially hinder comprehension (Blystone & Dettling, 1990; Sanchez & Wiley, 2006; van den Broek, 2010). The graphics in this study are no exception, and the connective features in the graphics could possibly lead a student away from the instructionally important ideas in the text. However, I only noticed one student, Fran, whose engagement with MW2 might initially be considered a seductive effect. Fran's only focus in MW2 was about trying to make sense of a turkey in a microwave oven while reading the text:

> Fran: [reads to end of paragraph 5]: …Nearly all of the foods you eat and drink have water in them(?), so microwaves can heat most foods, like hot chocolate and pizza.
>
> ~ Um, is that an oven or a microwave? <points to MW2> Because you can't fit a turkey in a microwave. It's too big.
>
> [continues to read, reading to end of paragraph 6]: That makes the *all* of the food molecules move faster. When the molecules in the food move faster, the food heats.
>
> ~MW-TA12. I still... isn't that <points to MW2; top right image> supposed to be an oven? Or a microwave? That's confusing because they should like make it a microwave like with pizza or a microwave with a...um, oven with, um, turkey. That makes me confused. Unless it's a small turkey. A really small turkey. [inaudible]_

This focus persisted, even later in the interview. Fran's responses to stimulated recall and metacognitive questions again referred to the turkey in the oven and no other ideas communicated by the prose and/or graphic.

> Me: And can you tell me a little bit about this <points to MW2> diagram?
>
> Fran: That a turkey fits into the microwave?

…[Later in interview]…

Me: And what made you decide to look at it <points to MW2>? What made you look at it there?

Fran: Because no how no way there's a turkey in the oven [laughs].

Fran was noticeably focused on the practicality of cooking a turkey in a microwave oven and nothing else.

Upon initial inspection, it seems Fran's attention to the turkey in a microwave oven might have "seduced" her away from making sense of any instructional ideas she read. However, I would argue that Fran's focus on the turkey was less an effect of MW2's connective feature than Fran's difficulty engaging with and comprehending the text. Recall that I described Fran and her prose-graphic engagement when characterizing students' missed opportunities. I showed how Fran struggled with, and failed to comprehend, both texts. I also noted that Fran's think-aloud comments for the *Cooking with Ovens* text suggested she was not focusing on the science ideas communicated by the prose and graphics. And I questioned whether attention to the graphics (at instructionally complementary opportunities) would support her access to, understanding of, or even internalization of, the science ideas communicated in each representation. Perhaps Fran, having difficulty as she did comprehending and focusing on the science ideas as she read the prose, could not engage with MW2 in any way except to relate the turkey and microwave oven to her experiences. Fran's experiences with the approximate size of a turkey versus a microwave oven were inconsistent with what MW2 showed. The connective features of MW2 did not "seduce" Fran away from the science ideas in the text. Unfortunately, they also did not "seduce" her *toward* the science ideas.

Researchers have cautioned educators about the ability of graphics to be negatively seductive. The graphics in this study are no exception. However, the suggestions provided by Rene, Jessie and Blair also show that students can be critical readers with an awareness of both graphics' roles and the roles of connective features.

<u>Summary: Prose-Graphic Engagement Via Connective Features</u>

In this section I described and highlighted connective features as prominent factors of students' prose-graphic engagement. I organized this section with respect to students' prominent display of their use of and awareness of connective features, as well as the value students placed on connective features. Students' use, valuing, and awareness of connective features occurred as a function of students' efforts to make sense of the prose, to make meaning of the text, and to make the text meaningful.

The consistent inclusion and application of connective features in students' comments as they discussed topics of understanding, usefulness, and interest show that students valued connective features as a means of making sense of, and supporting understanding of, the prose and entire text. Students also demonstrated use of and valuing of connective features by applying connective features apparent in graphics (MW2 and BB1), as well as applying connections to the graphics that lacked such features (MW1 and BB2). Also, when applying connective ideas to BB2 and MW1, students used connective features from the prose and/or introduced self-generated connections. I showed that applications of self-generated connections, if related to the science the ideas communicated by the graphic(s), could support students' science understanding. I also showed that self-generated connections that did not relate to the science could be a factor in supporting their interest, disinterest, or possible confusion.

In this section I also elaborated on students' inclusion of connective features as another facet of students' meta-representational competence. Students demonstrated knowledge of connective features through their recognition of apparent connective features' connective roles. Meta-representational competence was also demonstrated through students' critical responses on such features. Knowledge of connective features seemed helpful to students as they made meaning of the text and as they demonstrated interest in and efforts toward making the text meaningful. In these ways the corpus of data concerning connective features suggests the features as facets of students' strategic use of graphics *and* their meta-representational competence.

Summary of Findings About Students' Prose-Graphic Engagement

In this chapter I discussed findings about students' prose-graphic engagement when reading and making sense of science texts using four approaches. First I described students' engagement by reporting findings on students' attention to the graphics when reading the text. Second, I discussed cases of students' engagement in popular instances and instructionally complementary instances. Third, I described a phenomenon involving the texts' limitations and affordances and the bidirectional nature of prose-graphic engagement. Last, I discussed students' prominent inclusion and application of connective features as a major element in their reading processes and prose-graphic engagement. Of the findings, some are in agreement with existing literature (e.g., students were aware of the function of graphics to help readers who have difficulty reading and making sense of texts). Some findings complement and add to the literature (e.g., reasons why students might look to a graphic had been addressed, but the *differences between readers* had not been previously reported (viz., Hegarty, et al., 1991)). And some of the findings have not been identified in literature thus far (e.g., students' orientations toward, and use of, connective features in graphics).

In the next chapter I summarize the findings to describe and discuss students' prose-graphic engagement according to four recurring themes in this research: students' prose-graphic engagement is complex; characteristics of texts can afford or limit students' prose-graphic engagement and access to the science; students demonstrated facets of meta-representational competence; and students used reading comprehension strategies and also strategically used graphics.

CHAPTER 7
DISCUSSION & CONCLUSIONS

My study revealed characteristics of sixth grade students' engagement with the prose and graphics of science texts. Better understanding of students' engagement with the prose and graphics of science texts can ultimately inform designers and educators about ways to help students efficiently access and make sense of science ideas communicated by the texts' multiple representations.

Focusing on interactions among students' individual characteristics, textual characteristics, and prose-graphic engagement, my study addresses Moore and Scevak's (1997) proposal concerning the necessity of researching how students use graphics and prose when reading science texts and researchers' recent demonstration of the importance of providing "a better understanding of the information processing that underlie [sic] the comprehension of multimedia documents, particularly as it applies to learning" (Rouet, et al., 2008 p. 2). For example, researchers such as Schnotz (2008) have asserted that a thorough theory of comprehension must focus not only on the reader's cognitive processing but also on the reader's characteristics, the learning materials, the task, and other elements of the learning context.

To guide the study I used the following research and focal questions:

Research Question: How do students engage with prose and graphics as they read and make sense of science texts?

Focal Question 1: What patterns emerge with respect to sixth graders' overall engagement with prose and graphics while reading and making sense of science texts?

Focal Question 2: How do characteristics of each reader interact with how he or she engages with prose and graphics when reading and making sense of the texts?

Focal Question 3: How do characteristics of the texts interact with how readers engage with prose and graphics when reading and making sense of the texts?

I studied interview data focused around students' reading of, and comments about, two chemistry texts with prose and graphics. The interview data included think-aloud comments and responses to questions regarding stimulated recall, prior knowledge, interest, and comprehension. I used this data to identify and characterize mechanisms of students' prose-graphic engagement. The research questions and the use of interviews address Ainsworth's (2008) suggestion that researchers need to assess what happens during learning with multimedia texts, and not only outcomes. Ainsworth also emphasizes the relevance of case-based, qualitative observations to explore the complex processes that students perform as they use multimedia texts.

The use of descriptive research in my study also addresses a need articulated by Gambrell and Jawitz (1993), who stated, "Clearly, research that explores ways in which readers respond to and interact with text holds much promise for expanding our theories of reading process" (p. 266). The authors' message has also recently been restated with emphasis on using texts with multiple representations. For example, Cromley and colleagues (2010) stressed the need to analyze the cognitive processes involved in coordinating information in prose and graphics. Additionally, McTigue and colleagues (2010; 2011) utilized interviews to determine students' ratings and use of graphics that were extracted from science texts.

Organization of Chapter

I first organize this chapter into four sections based on recurring themes in the research: students' prose-graphic engagement is complex; characteristics of texts can afford or limit students' prose-graphic engagement and access to the science; students demonstrated facets of meta-representational competence; and students used reading comprehension strategies and strategically used graphics. Within each thematic section I summarize and synthesize the findings. I discuss specific findings in each section. Although findings are separated into their respective sections, they integrate and connect with each other, together providing a holistic picture of students' prose-graphic engagement. However, I make the separations in order to focus on the themes themselves.

Within each thematic section I also discuss the significance and implications of the findings. The implications are focused on science curriculum development and the goals of supporting readers not only to engage with prose and graphics, but to also access the science ideas communicated by each representation.

After the thematic sections I summarize the implications. I then end the chapter by identifying limitations of the study and directions for future research.

THEME 1: STUDENTS' PROSE-GRAPHIC ENGAGEMENT IS COMPLEX

Students' engagement with any text is complex, as factors of the student, the text, the context of the task, and the overall context are negotiated as a student makes meaning from and comprehends a text. This complexity was apparent in the findings of this study.

Summary and Synthesis: Students' Prose-Graphic Engagement is Complex

Students in this study engaged with the prose and graphics in some similar ways, regardless of individual characteristics and texts. All 20 students demonstrated and reported engagement with at least one graphic while reading the texts. All 20 students looked at one or more graphic as they read each science text. And most students showed interest in the graphics before, during and after reading the texts.

Students also engaged with the prose and graphics in some different ways due to differences in reading achievement and prior knowledge. Students' average frequencies of attention ranged from 3 to 7.5 instances. However, most struggling readers indicated looking at the graphics less frequently and less consistently compared to intermediate and proficient readers. Also, readers with average prior knowledge gave less attention to graphics than readers of high prior knowledge.

Multiple factors in readers' prose-graphic engagement were apparent. The multiple factors seemed to interact synergistically, collectively contributing to students' engagement with the graphics. However, in some situations single factors (and in other situations, a set of factors) seem to have more influence on the students' engagement.

For example, during the pre-reading task, more than half the students used the graphics to determine their level of interest in, and/or to predict the content of, the texts. However, students were more likely to use the graphics to determine their interest than to make predictions about the texts. In the pre-reading situation, determining interest may therefore have been a more influential factor in students' engagement with the graphics. When students indicated using the graphics in other situations (e.g., while reading the texts), they reported interest as a reason why they looked at a graphic. However, they more commonly reported other reasons, such as salient features in the graphics.

A complex interaction between students' low prior knowledge *and* reading achievement was also evident in their frequencies of attention to the graphics. Students with low prior knowledge seemed to follow no pattern in their frequency of attention to the graphics. However, students with low prior knowledge and with below average frequencies of attention were struggling readers. On the other hand, students with low prior knowledge who were above average in their frequencies of attention were intermediate and proficient readers.

Low prior knowledge may have also been a factor in the intermediate and proficient readers' use of graphics in most instructionally complementary instances. This pattern, involving the interaction of students' reading achievement, *low* prior knowledge, and frequency of attention to graphics (both in general and in instructionally complementary instances), also shows how two specific student characteristics seemed to interact synergistically, leading to students' use of graphics at specific instances in their reading process.

Significance and Implications: Students' Prose-Graphic Engagement is Complex

Although only suggestive due to the small number of students in this study, the findings are evidence of the ways students' prose-graphic engagement are complex. The findings pertain to recent reports expressing the need to incorporate multiple dimensions of the learning context in order to provide a full theory of comprehension for students' use of multi-representational texts (e.g., Schnotz, 2008).

Implications of the findings include the need for science text design that supports students' engagement with and/or access to science ideas in the prose and graphics.[25] Theoretically, science text designers should determine goals for including a graphic and utilize design strategies to achieve the goal.

One example of how alignment of text design with student support goals is necessary is suggested by the finding that students were more likely to use the graphics to determine their interest in the text than to make predictions about the text. Based on that finding, text designers who want students to be interested in and engage with the text before reading might thus incorporate features of graphics that are potentially interesting (e.g., salient features such as color, and features that students may have experienced previously). On the other hand, if a designer's goal is to help students predict the content of a text, designers might focus on the use of labels or titles in the graphics that match the headers of the prose, as students may use such cueing elements to help make predictions about the text.

As another example, text designers who want to support students' access to the science information in the representations might use the findings on the differences in students' use of graphics according to prior knowledge and reading achievement, and the synergistic interactions of factors such as interest, reading achievement and prior knowledge. Science text designers might therefore consider applying the same principles of "considerateness" (Armbruster & Anderson, 1985) to the graphics as they would apply to the prose in order to support students' access to the science information in the representations.

Theme 2: Characteristics of the Texts Can Afford or Limit Students' Prose-Graphic Engagement and Access to the Science

Features of the prose and graphics can either afford or limit not only students' prose-graphic engagement, but also their access to the science in the texts and consequently, students' comprehension. I discuss findings on students' engagement with prose-graphic features in popular instances when students used the graphics and

[25] I include *engagement with* the prose and graphic and *access to* the science ideas because students may engage with a representation, and make meaning from it, but they might not utilize or make meaning of (i.e., access) the science information that the representation communicates.

instructionally complementary instances, as well as students' orientations toward connective features in the graphic.

Summary and Synthesis: Ways Characteristics of the Texts Limited or Afforded Students' Prose-Graphic Engagement and Access to the Science

Popular Instances

Most students tended to look at the graphics in three popular instances: before reading each text, after reading each text, and around the sixth paragraph of the *Cooking with Ovens* text. These instances seemed popular because of the graphics' saliency and spatial placement (e.g., MW2 is a large graphic set between paragraphs, allowing the linear flow of the prose to continue). This finding relates to Mayer's (1997; 2001) spatial contiguity principle. This principle is based on the assertion that students learn better when the words and graphics are placed closer together and/or presented simultaneously. Possibly students *learn better* when the representations are placed closer together because students are *more likely to attend* to both modes of representation in those situations.

Other possible factors influencing each popular instance were students' interest and curiosity about the graphics (before reading), the graphic's complementary relationship with prose (around the sixth paragraph), and cognitive efforts to read captions in graphics (after reading). Cognitive effort as a possible reason for the graphics' (especially BB2's) popularity after reading is in line with results of studies on cognitive load and design principles that reduce cognitive demand. For example, principles about the expressiveness of displays (such as the principle of capacity limitations) (Hegarty, 2011) and about perception of displays (such as the principle of salience) (Hegarty, 2011) take into consideration limitations in working memory and making important information salient. These principles were not applied to the design of BB2. Therefore, students' expressions of cognitive effort to use BB2 and the popularity of looking at BB2 *after* reading are further evidence of how students might engage with poorly designed graphics.

Instructionally Complementary Instances

In this study, struggling readers tended not to use graphics as readily in instructionally complementary instances regardless of their prior knowledge, whereas the intermediate and proficient readers with *low* prior knowledge indicated attention to the graphics in most (four to six of six total) instructionally complementary instances.

Also, of the 9 students who indicated attention to the graphics in most (four to six of six total) instructionally complementary instances, 8 students almost always included the complementary science ideas in their think-aloud comments. This suggests that the readers may have been able to access the information in both representations and may have used prose and graphics together as they made sense of the science ideas in the text.

The 11 readers who indicated little attention to the graphics in the instructionally complementary instances demonstrated various characteristics in their engagement solely with prose. Some students (a) seemed to struggle in reading and making sense of the prose. Students demonstrating this characteristic seemed to struggle with comprehending the prose, to be disengaged from the task, and/or to show confusion. Students in this situation might not access the instructionally complementary ideas in the graphics even if they did use them.

Some students (b) seemed to be making sense of the prose but asked questions that the graphics could help answer. On the one hand, the situations in which this characteristic emerged could be deemed as "missed" opportunities to access the instructional information. On the other hand, students who "missed" opportunities may not have been able to access the information due to the graphics and/or individual characteristics. Other students seemed to (c) comprehend the prose and might not have needed to access the instructionally complementary ideas in the graphics in order to fully comprehend the text.

Students seemed to misinterpret the prose especially at the instances in which the *Cooking with Ovens* prose (paragraphs three and four) and MW1 were complementary. When readers had low prior knowledge and/or were struggling to make sense of the text, their misinterpretations of the prose, coupled with the limitations of and difficulty in accessing information from the prose and graphics, could to lead to a disadvantageous domino effect. That is, misinterpretations of, or failure to comprehend, the prose may lead to misinterpretation of and/or confusion with the graphic, which can then contribute to lack of full comprehension of the text. However, this domino effect might not occur with proficient and intermediate readers, as they may be able to correct the misinterpretations themselves.[26]

Students' Orientations Toward Connective Features

Use of connective features in graphics was an integral factor in students' prose-graphic engagement.[27] Students used the connective features in graphics, they valued the features, and they demonstrated awareness of the connective features. Students' demonstrated orientations toward the connective features in graphics were in the context of supporting their interpretations of, understanding of, and interests in the text.

Students not only used connective features apparent in BB1 and MW2, but also applied connective ideas to MW1 and BB2 (the graphics that lacked connective features). By applying connective features, the students either used connective ideas from the text and/or used their own, student-generated connections. In most cases the applications of connective ideas to MW1 and BB2 were strategic in order to support interest and/or understanding of the science texts. Students' application of connective ideas that also related to the science ideas communicated by the graphic(s) seemed to support their access to, and possibly their understanding of, the texts' central science ideas. When students applied connections that were not related to the science ideas, their access to the science ideas was not as apparent as other factors of engagement with the text, such as their interest, disinterest and/or confusion.

Students' demonstrated orientations towards connective features in MW2 and BB1 suggest that students used such features to mediate their engagement with other science-related elements in the graphic (e.g., molecules for MW2). By mediating engagement with the science-related elements, connective features also seemed to support accessibility of science information in graphics. Connective features in graphics

[26] In the following section I describe students' responses to the limitations of the texts as a facet of meta-representational competence.
[27] In the following section I continue to discuss students' awareness and orientations to connective features as facets of students' meta-representational competence.

therefore can be an affordance of the text – a potential tool to mediate students' access to science ideas.

Students potentially could focus on connective features in graphics, but not use them to engage with the science ideas. For example, one may consider MW2 (a graphic with connective features) as a "poor" graphic because it is "full of irrelevant details that distract (e.g., the antenna)" (C. Delgado, personal communication, February 23, 2008). This critique of MW2 was made when discussing with colleagues my observation of a reader in this study questioning why an antenna was in the microwave. The critique suggests that connective features have the potential to be *seductive*.[28] The possibility that connective features in graphics can be seductive raises the question of whether connective features should be included or excluded in graphics. Of course the answer to this question is not simple, as mediation or seduction depends on multiple factors, not just the feature itself. In this study the little evidence of possible seduction (e.g., Fran's focus on the turkey in MW2) seemed to occur based on multiple factors, including student characteristics such as previous experiences and reading achievement.

Connective features in science learning environments are based on the premise that the features clearly *connect* to the science ideas to be learned (Krajcik, et al., 2003). This premise is supported by my findings regarding students' application of connective features to MW1 and BB2 (the graphics that lacked connective features). Patel and Xipil demonstrated how some students applied connective features that related to the science ideas communicated by the graphic(s) and how the connective features seemed to support students' science comprehension. However, other readers applied ideas that were not related to the science, and that possibly hindered their engagement with the graphic and ability to access the science information. Therefore, inclusion of features that clearly connect to the science ideas communicated in the graphic may provide less possibility of distraction, and more accessibility of, the texts' science ideas.

In this study connective features also seemed to support students' interest in reading science texts. Students commonly referred to the graphics before reading to determine their interest in the text, and students referred to connective features as a

[28] In Chapter 2 I mentioned that graphics can have seductive details – features that not only communicate irrelevant information with respect to the topic of the text, but also lead one's attention away from the major message (Blystone & Dettling, 1990; Sanchez & Wiley, 2006).

means to support interest in the text. This finding supports Halkia and Mantzouridis's (2005) findings that students' interest in graphics may have some influence on their reading processes. Possibly the connective features' role in graphics to support interest in the text might also provide an avenue for students to further engage with the prose, graphics, or both, thereby potentially supporting access to the science ideas in the text.

Significance and Implications: Ways Characteristics of the Texts Limited or Afforded Students' Prose-Graphic Engagement and Access to the Science

Popular Instances of Attention to Graphics

Findings about the popular instances of attention are significant in that they help to better understand what students tend to do, whether formally or informally taught, when reading science texts with prose and graphics. Science curriculum designers might integrate the findings about popular instances of graphic use with previously reported design principles that focused on supporting students' learning. For example, the findings show that whether an instructed or independently acquired practice, most readers strategically use the graphics before reading. This pattern, when used with principles such as the contiguity principle (Mayer 1997; 2001), suggests that placement of a graphic in an area that allows a reader to use the graphic before reading and that is proximate to its complementary prose could benefit both engagement and learning of the texts' central ideas. Additionally, findings on students' use of graphics before reading to determine interest, when utilized with the relevance principle and the principle of salience (Kosslyn, 2006, as cited in Hegarty, 2011), may suggest science text designers should incorporate salient features in the graphics that can be both potentially interesting *and* relevant to the central science ideas in the text. Doing so may again support both engagement with the representation(s) and science learning. For example, in this study salient and potentially interesting features (e.g., the *big* microwave oven; the *colored* circles) seemed to support students' engagement and interest in the graphics even before reading the text. Both the microwave and the circles (in those instances where students correctly determined that the small ones are molecules) were relevant to the central ideas in the *Cooking with Ovens* text. However, MW1 and MW2 could have been improved by making the molecules more salient (and interpretable as molecules with varied speeds), and by either limiting or making less salient the less relevant parts. To follow the principles established above, the designer will need to first determine what is and is not relevant to the text.

Another implication of my findings supports previously reported design principles includes the placement of a graphic in line with the prose, similar to MW2, for paper-based print texts. This implication involves principles of saliency and contiguity, as MW2's size and placement in the middle of the page, and relevance to the prose around it, may support students' engagement. However, as reported in this study, MW2's popularity was most likely due to students following the linear flow of reading and therefore looking at the graphic that lay between paragraphs.

Another, less apparent, implication of the findings involves the need for design of instruction around reading texts with poorly designed graphics – that is, graphics that are complex and cognitively difficult (and thus take up working memory). Students' demonstrations the cognitive difficulty in using BB2 while reading suggests the need for instructional designers and teachers to incorporate instruction about how to compensate for poorly designed texts – or texts in which the graphic is poorly designed. This type of instruction can help students' access to the information and possible integration of the graphic and the prose regardless of when in the reading process the students might use the graphic.

Instructionally Complementary Instances

My findings regarding instructionally complementary instances are significant because they highlight the consideration of the needs of students with respect to their access to the instructional information from both representations. The findings also raise questions about instruction and how to help students access information from graphics. A general question is, *how can instructional materials help readers to engage with the science ideas in one or the other (or both) representations?* Other questions include, *how might we help students access information from the graphics, especially when they are already having difficulty accessing information in the prose?* Also, *in situations of struggle, would accessing the information even support their comprehension of the text?*

And, *is it acceptable for readers not to engage with and access information from the graphics in instructionally complementary instances when the readers already seem to comprehend the text's central science ideas?*

My findings also raise questions about science text design, such as, *what does it mean for a graphic to be "effective" when the needs of each reader vary?* And, *how can the prose and graphics support struggling and/or low prior knowledge readers in accessing the science ideas in representations*? Some research has identified ways to help readers (e.g., DeFrance, 2008). However, addressing these questions also requires knowledge about which characteristics of the prose and graphics are limiting struggling readers' access to the science information.

One implication of my findings regarding instructionally complementary instances is that instructional designers and teachers should consider the types of information that should be taught and/or introduced before reading the texts. This implication is based on the following premise: In my study a level of engagement with the science in the text seemed necessary in order for struggling readers (or readers having difficulty in reading and making sense of the prose) to access the information in the graphic. Possibly intermediate and proficient readers can access the information on their own by reading only the prose, but struggling readers need help with the prose if they are to access information in the accompanying graphic.

This premise may impose a circular problem – that is, in order to access the instructional information one must first be engaged with the science ideas, but to be engaged with the science one must be able to access the instructional information. Yet literature about students' prior knowledge and their comprehension of graphics suggests possible solutions. For example, Canham and Hegarty (2010) showed that students spent more time with pertinent information and less time focusing on extraneous information after instruction. The authors stated that their finding demonstrates how "attention to visual displays can change significantly with just a brief amount (ten to fifteen minutes) of instruction that is conceptual rather than procedural in nature, that is, a type of instruction that is typical in geography and other science classrooms" (p. 162). Instruction that could engage the students with the science ideas central to the text (and even incorporate graphical signs and systems similar to the graphics in the text) before students read the text might therefore help readers who would have struggled with reading the prose. The instruction might also help readers to access the science information in both the prose and graphics. However, the accessibility of the texts must also be considered (especially accessibility of the instructional ideas communicated in both the prose and graphics and the needs of the students to access and engage with the information). If the science ideas communicated by the text are inaccessible or confusing to the reader, then even prior instruction might not help readers.

Accessibility is another implication: designers must focus on accessibility of the instructional ideas for *both representations* (i.e., prose and graphics) and stress the need to analyze critically ways prose might help and/or hinder interpretation of the graphics and vice versa. As this study showed, situations might occur in which readers may need to comprehend the prose in order to correctly access the science information in the graphic. It is therefore important for science educators to recognize and be aware of science reading situations that, whether subtle or pronounced, that might lead to difficulties in making sense of and possibly in comprehending the text. For example, for at least one student, the inconsistent meanings of the color gradients within MW1 (i.e., between the top and bottom images) seemed to promote confusion about the meaning of the different colored molecules. Many students also misinterpreted the molecules as being *hot*. This type of misunderstanding possibly occurred because of the inconsistent meanings of the colors in MW1, because of the phrase *hot air molecules* used in the prose, and/or because the student held some incorrect prior knowledge about molecules being hot and cold.

Mayer (2001) reports that graphics can help struggling readers or readers of low prior knowledge and that graphics can help struggling readers more than the proficient and/or high prior knowledge readers. Mayer's findings could be misinterpreted, leading one to assume if a graphic is present, readers will better comprehend the texts. This study, in contrast, cautions that some graphics' proven "effectiveness" in supporting comprehension does not mean that struggling readers will engage with the prose and graphics together for full potential in understanding the science. Also, teachers, in being aware of this cautionary finding, might consider directing instruction toward engaging with and accessing information from prose and graphics together when teaching reading of and/or assigning reading of science texts. This can be done through implementing graphics as a tool to use just as one uses reading strategies, as discussed in a later section.

Students' Orientations Toward Connective Features in Graphics

Although connecting science to students' lives has been an important goal for science educators (viz., Rivet & Krajcik, 2008), there has been little focus on possible connections as features in the graphics of science texts. As discussed in the theoretical perspective, the commonly called contextual features have been used in science education as part of the instructional environment and as features mainly in the prose of science texts.[29] However, the role of these features as an integral element in students' prose-graphic engagement as they make sense of science texts has not been recognized in literature thus far.

Students' orientations to connective features in graphics convey connective features as a potentially mediatory tool in students' reading of science texts. One implication of these findings is therefore to suggest incorporation of connective features within graphics as ways to (1) mediate students' access to science ideas, and (2) scaffold students' use of scientifically accepted signs and symbols in the science domain. As described in the theoretical perspective and literature review, the use of connective features has already been applied to many instructional environments to support students' learning. Embedding connective features in graphics is an extension of the use of connective features in instruction.

Here I discuss the first role – the potential of connective features to mediate students' access. (In Theme 3 I discuss the second role, connective features as scaffolds.) The construction of texts (prose and/or graphics) that make science more accessible to students is a major goal of a text designer. By potentially supporting students' access to science ideas, connective features in graphics could be utilized for more successful development of science texts. However, this implication involves criteria in order for

[29] I noted in Chapter 2 that the texts in this study followed the IQWST reading materials design principles, one of which is to apply and connect real-world examples. The focus of such inclusion in IQWST principles however, was with respect to the prose, whereas the findings in my study involved the connective features embedded in the scientific graphics. I also discussed Martin's (2002) use of images that provide context in science texts, yet the graphics used in Martin's study contained no specific science ideas. Here I discuss connective features as elements in graphics that provide science ideas.

connective features to be mediatory. First, in order to be effective as a connective feature, students must connect the features to their own prior knowledge (including prior experiences) and their interests. Therefore, designers must be cognizant of the ways readers utilize connective features. As designers cannot determine a priori with what features students might relate, they can only rely on features that may be experienced by the general (and, in some cases, local) population. For example, "pizza" (as used in the prose of the *Cooking with Ovens* text) could have been used in the graphics as a connective feature. Alternatively, possibly texts and/or teachers can lead the reader to "choose their own" everyday connective feature to be correctly applied to a graphic.

Second, connective features must clearly connect the everyday elements to the science ideas communicated in the graphic. The everyday element-science idea connections would be determined based on the science domain. In this study with chemistry texts, the connections involved a macroscale-nanoscale connection. For example, the turkey (and its "heating") was the everyday element at the macroscale level, and the molecules (and their "movement") were the science explanation at the nanoscale level. These connections are commonly used in instruction, especially in chemistry education (e.g., Stieff & McCombs, 2006). However, there has been little focus on the use of the features as a means to support students' access to science as they read the science texts.

Third, designers must continue to be aware of and reduce the possibilities of embedding features that may "seduce" readers away from the texts' central science ideas. Ways to identify possibly seductive features include, for example, a detailed critique of the features' consistency with the everyday experiences of the general population. For instance, students such as Fran demonstrated a fixation as to whether a turkey can fit into a microwave oven. The image of the turkey as being cooked in a microwave oven is inconsistent with the general population's use of a microwave oven (and of the general population's techniques for cooking a turkey). This inconsistency seemed to limit Fran's access to the science ideas in the graphic.

THEME 3: STUDENTS DEMONSTRATED FACETS OF META-REPRESENTATIONAL COMPETENCE

Just as meta-representation and meta-representational competence is important for students' use of representations in science and their learning and understanding of science content (diSessa, 2002, 2004; diSessa & Sherin, 2000), it is also important with regard to reading science texts. In this study students show multiple facets of meta-representational competence in the context of reading science texts.

Summary and Synthesis: Demonstrations of Meta-Representational Competence

Similarities and Differences in Demonstrations

In this study, students were *similar* (regardless of individual characteristics) in their demonstrated awareness of the function of graphics as a source of help in making sense of the texts if difficulty arose. Most students, regardless of reading achievement, demonstrated this awareness when they suggested using graphics to help classmates read and make sense of the science texts. This finding was consistent with the findings of Craig and Yore (1995), who termed the students' awareness as "metagraphical awareness." As mentioned in Chapter 2, in this study metagraphical awareness is a facet of meta-representational competence.

Students were also *similar* in demonstrating meta-representational competence in two categories of reasons why they looked at the graphics. The categories included looking at a graphic (a) because the graphics illustrated information about the prose and (b) to take in information in the graphic.

Yet students also *differed* (with respect to reading achievement) in their demonstrations of meta-representational competence. For example, most proficient readers' reasons why they looked at graphics included (a) to check a mental representation and/or reactivate information, (b) to gain a better understanding, and/or (c) to take in information about the text. However, less than half of the struggling readers provided reasons that fell into these categories.

These findings align with Hegarty and colleagues' report (1991), showing students *do* use the graphics for reasons Hegarty and colleagues suggest. Yet the findings also add to the research by highlighting that a *difference* seems to occur among readers. For example, most students seemed aware that graphics can help if they are having *difficulty understanding* the text, and they might even use the graphics in such ways. However, it seemed only certain students (mostly proficient and intermediate readers) were aware of, and might use, the graphics to help them *better* understand (i.e., extend and/or clarify their understanding), even when already comprehending the text.

Students' Prose-Graphic Engagement with Respect to Limitations of MW1

As discussed in Theme 2, students misinterpreted and/or were confused by the *Cooking with Ovens* prose and by MW1. The students also seemed to respond to their confusion and the limitations of MW1 in different ways, thereby demonstrating different facets of meta-representational competence. For example, Haiden, in correctly interpreting the little circles of MW1 as molecules (and the different colors as representing different molecules), demonstrated her knowledge and use of the sign systems for molecules. This type of meta-representational competence could also be identified in other science learning contexts besides reading. However, in the context of reading and the limitations of the prose and text, Haiden was not able to utilize either representation to reduce confusion. On the other hand, both Kris and Sam demonstrated their use of the prose to help them (and as Kris shared, to help other classmates) to make sense of the graphic. This demonstration shows a different facet of meta-representational competence – that is, understanding of the integrative and bidirectional roles of the prose and graphics such that each representation can be used to help support understanding of the other representation, and the text as a whole. This facet of meta-representational competence is addressed by Schnotz and colleagues (2011). They explain the importance of readers' competence in integrating the prose and graphics and introduce a question about supporting such competence:

> When learning from such materials [textbooks that include schematic diagrams or graphs], students are expected to use text and pictures as complementary sources of information because they have to integrate verbal and pictorial information for the construction of mental representations of the learning content. From an educational point of view the question arises: How can students' competencies for integrating text and pictures be promoted? (p. 104)

Kris's and Sam's demonstrations of their meta-representational competence about the integrative and bidirectional roles of prose and graphics revealed ways that some students may *already* be competent in integrating prose and graphics when reading science texts.

Students' Orientations Toward Connective Features in Graphics

Students' awareness, inclusion, and valuing of connective features in graphics are also facets of their meta-representational competence. For example, students demonstrated meta-representational competence when applying connective ideas to BB2 and MW1. Students also demonstrated meta-representational competence through their awareness of connective features in graphics. This awareness was demonstrated by some students who seemed to recognize the roles of the connective features in MW2 and BB1 as connecting to students and their experiences in and out of the classroom. Other students also demonstrated awareness of connective features through their critical assessment of the graphics. Some suggested simplifying the graphics and/or taking away certain connective features to support understanding. However, most students' critical assessment of the graphics involved *including* connective features to support understanding.

diSessa (2004) also recognized students' orientations toward graphic elements that I would consider as connective features in his report about meta-representational competence and students' "native competence." diSessa discussed the elements with respect to realism and abstractness and also described native competence as a developmental pattern – realistic displays are more valued early on. Indeed, experiences with representations, and the evident transition of the forms, features, and uses of representations from early grades to middle and high school grades, may explain why students in this study were aware of and used connective features in graphics when making sense of the science texts.[30] However, in the later elementary and the middle-school years, the forms, features, and uses of representations change as science ideas become more complex. Kress and Van Leeuwen (2006) recognized this change as they

[30] As mentioned in Chapter 2, early childhood learning experiences frequently involve representing (e.g., pretend play, Piaget, 1969). Vygotsky (1978) also described children's use of signs and symbols as a socialization process and cognitive assimilation to reality. Early reading experiences also involve directly connecting a picture to a word or idea.

described the increasing objectivity and declining emotive involvement (between the reader and graphic) in graphics in textbooks from grade school to middle school.

diSessa (2004) also discussed students' orientations toward real versus abstract elements in representations, stating,

> Realism plays into representational issues in complex and *frequently problematic* [italics added] ways. For example, we were surprised at how strong a preference students had for realistic presentation of landscapes… In fact, some students expressed strong commitment to realism even when we asked them to consider representations only for the scientific purpose of depicting altitude. (p. 321)

Here diSessa focused on instances in which students' preference for realistic representations of landscapes and altitude were *problematic* – most likely because such preferences limited their competence in using certain representational signs and systems such as contour lines. diSessa also described students' different representations of a car in motion as changes in abstractness. He considered a "concrete" part of the illustration of motion (i.e., connective feature) that a student might consider important towards the communication of specific information as *functional residue*.[31]

Although diSessa (2004) reported students' applications of and preferences for realistic representations as functional residue, he did not focus the discussion on how science educators might use the aspect of functional residue as a means to *help* students transition the way they represent phenomenon. In my research, students seemed to use connective features (which in some cases might occur as or be student-generated via functional residue) as mediating agents to connect to their prior experiences *and* provide a referent that they might understand, yet as novices, might not yet apply themselves.

Significance and Implications: Demonstrations of Meta-Representational Competence

Besides metagraphical awareness, little has been said about students' meta-representational competence as they read science texts. In my study, the students' demonstrations add to our understanding of ways they are competent in their knowledge about and use of graphics. In other words, students' demonstrations add to literature

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[31] diSessa (2004) first defined a *functional niche* as "a context that makes a certain pattern of demands on a representation." The author then described *functional residue* as a concept in which "properties of old functional niches show as maladaptation to new functional niches." (p. 307)

about students' meta-representational competence, specifically in the context of making sense of science texts.

Just as meta-representational competence in the context the science classroom can inform instructional design, so too can the identified facets of meta-representational competence in the context of reading science texts. One practice these identified facets may suggest is instruction for students about using graphics in similar ways that teachers now instruct use of reading strategies. (This can include embedding instruction of strategic graphical use within already structured instruction about reading strategies.) The differences I reported among struggling readers versus the intermediate and proficient readers suggest that some facets of a student's meta-representational competence in reading relates to his or her reading achievement. Therefore, just as reading strategies are taught and may support students' metacognition in reading, teaching graphical use in ways similar to, and possibly along with, reading strategies might also support students' meta-representational competence. This is a possible answer to a question posed by Schnotz and colleagues (2011): "How can students' competencies for integrating text and pictures be promoted?" (p. 104). This is also further explored in the next section (Theme 4).

Another suggested practice is for science text designers to embed connective features in graphics as a means to scaffold students' use of scientifically accepted signs and symbols in the domain. The transition of the forms and features of graphics in science textbooks and in the general applications of graphics in the science classroom in higher grades provide the basis for using connective features as both a reasonable and instructionally supportive strategy to help students access and make sense of the science ideas communicated in the text. Scientific graphics can and do employ signs and symbols that are commonly used in the science fields to communicate information. The inclusion of connective features could scaffold students' experiences in using the established representational systems. This notion of connective features as scaffolding the practice of representation also may help students in their transition from a subjective perspective (in which relationships with one's world is prominent) to an objective perspective (in which relationships of the science ideas are prominent). It is possible that after students develop the scientific practices of interpreting and using established signs and symbols, the connective features would not be needed.

diSessa (2004) stated, "The proverbial developmental transition from concrete to abstract appears to have a degree of validity concerning MRC [meta-representational competence]. However, the story is not simple" (p. 295). The findings in my dissertation begin to elaborate on this point not only by highlighting students' orientations to connective features, but also by showing that such features can possibly be used to support students' transitions from real-world connections to the "abstract" science representations that scientists tend to use. Yet if connective features are to be utilized in text design, then students may need support with developing their meta-representational competence with respect to connective features, such as how to use the connective features and how to avoid misusing them in ways that hinder comprehension. This suggests that teachers must be cognizant of the everyday depictions already in the graphics of scientific texts (including whether the depictions have connective features based on the criteria described in Theme 2) and students' possible successful and unsuccessful engagement with the features. My study's findings that some students showed meta-representational competence via a critical stance toward the connective features in MW2 and BB1 show that, whether formally or informally learned, students *can* incorporate such awareness and knowledge about the graphics and their features when reading and making sense of prose and graphics.

THEME 4: STUDENTS USED READING COMPREHENSION STRATEGIES AND STRATEGICALLY USED GRAPHICS

Summary and Synthesis: Reading Comprehension Strategies and Strategic Graphical Use

Joint and Independent Use

In this study students demonstrated strategic use of graphics and strategic use of the prose and graphics together as they made sense of the science texts. In the theoretical perspective I discussed that scholars have used two approaches as they studied students' reading comprehension strategies. Some reports discussed students' use of strategies on each representation (prose and graphic) individually (e.g., Cromley, et al., 2010; Schlag & Ploetzner, 2011). Other reports discussed students' use of graphics to help in performing reading strategies (e.g., Craig & Yore, 1995; Yore, et al., 1998). My study of students' think-aloud comments around moments they reported and/or demonstrated looking at a graphic incorporated both approaches.

Of the 20 students in this study, 6 showed that they focused solely on one or more graphics during their reading process. As these students were interpreting the graphics, they seemed to apply strategies (some of which were also used while reading the prose, e.g., making inferences). Students' application of strategies to interpret solely the graphic seemed to be a distinct step in accessing information. It is possible that application and integration of information from the prose and graphics could occur as the distinct processing of graphics occurs.

Most students in this study, including those who applied reading strategies to their interpretation in of the graphics, also used the graphics jointly with reading comprehension strategies throughout their reading process. The cases in which students strategically used graphics jointly with reading comprehension strategies may to be related to Hegarty's (2011) description of graphics as an "external storage of information." As an external storage, readers can together utilize the graphic *and* reading comprehension strategies such as summarizing, referring to prior knowledge, anticipating, and asking questions.

Comparable Characteristics

Graphics generally have been recognized as tools students should use to describe ideas in the text, clarify ideas, etc. In fact, these ways to use graphics are promoted by the Common Core State Standards Initiative (2010). Although graphics are not the same types of tools that reading comprehension strategies are, strategic use of graphics and use of reading comprehension strategies are comparable.

One comparable characteristic is that the readers in this study strategically used graphics *throughout* the reading process, just as readers can use reading comprehension strategies throughout the reading process. In this study, students indicated looking at the graphics while reading, and doing so for specific reasons (i.e., the looks were goal-directed). Also, students demonstrated awareness of their use of the graphics. The findings correspond to Afflerbach and colleagues' (2008) definition of reading strategies: as "deliberate, goal-directed attempts to control and modify the readers' efforts to… construct meanings of text. The reader's deliberate control, goal-directedness, and awareness define a strategic action" (p. 368).

A second comparable characteristic is that differences in prose-graphic engagement occurred between different readers – specifically struggling versus intermediate and proficient readers – in ways similar to differences in readers' use of reading comprehension strategies. For example, in this study, struggling readers indicated *less* frequent attention to graphics than intermediate and proficient readers. Most struggling readers also tended to use the graphics in few (zero to three of six) instructionally complementary instances. Most struggling readers were also *inconsistent* in their general instances of attention across texts, whereas most intermediate and proficient readers were consistent. These differences between struggling readers and the intermediate and proficient readers suggest ways intermediate and proficient readers might strategically use graphics (and ways struggling readers might not do so) while reading and making sense of the texts. For example, the consistent readers might have their "own" (possibly instructed, possibly independent) routine ways of using graphics while reading that are also dependent on their own engagement with the text. In other words, the possibly routine ways are dependent on their own metacognitive processes and needs, interests, and previous experiences. Graphic use might have therefore been used strategically – as one of the many tools in a reader's repertoire, with its use being dependent on the reader's metacognitive processes and individual needs.

The differences between struggling readers and intermediate and proficient readers also extended to the reasons why they looked at graphics. Few struggling readers articulated reasons that involved (a) checking their mental representation, (b) gaining a better understanding, and (c) taking in information about the text, whereas many intermediate and proficient readers included such reasons. This study did not discern if students' reports reflected their actual use of the graphics or if the students' reports were a reflection of them being more or less metacognitive. However, differences in meta-representational competence suggest possible ways readers might differ in their strategic use of graphics while reading and making sense of texts.

In comparison to the findings about students' use of graphics, reading researchers have long understood the differences between proficient and struggling readers with respect to their use of reading comprehension strategies. For example, Kletzien (1991) reported that "good and poor comprehenders" used strategies such as using key vocabulary, rereading, making inferences, and using previous experiences when completing a cloze-related task. However, struggling and proficient readers differed in their strategy use as the text became more difficult. Kletzien noted that, "as the passage difficulty increased, good comprehenders used more types of strategies and used strategies more often than the poor comprehenders did" (p.67).

Significance and Implications: Reading Comprehension Strategies and Strategic Graphical Use

Students' joint *and* independent use of reading comprehension strategies with strategic graphical use shows that studying students' prose-graphic engagement with one or the other approach may limit understanding of how students use graphics when reading science texts. In fact, possibly the two mechanisms might be best utilized together as a means to support students in reading texts with prose and graphics.
For example, using reading strategies when reading and/or interpreting each representation individually may help if correct science information is inaccessible using only one of the representations. It might also support instances when the graphic is too complex or poorly designed and therefore cognitively difficult.

Students' joint *and* independent use of the two types of tools (reading comprehension strategies and graphics) also provides implication questions for instructional designers and researchers of science reading. For example, *should instruction include both mechanisms to support students as they read science texts?* And, *how might such instruction be implemented?* Indeed, to successfully instruct students to use reading comprehension strategies, the instruction must connect the underlying purpose(s) with the use of each strategy (Palincsar & Schutz, 2011). Perhaps such a focus could answer the questions I pose.

Additionally, my findings suggest instruction should combine the use of graphics with reading comprehension strategies – in a sense, consider graphics as a tool, similar to reading comprehension strategies in that they have comparable characteristics.

This implication of the findings contributes to the discussion of the need to support readers in using the tools available to them – both graphics and reading comprehension strategies together – to engage with, access information from, and comprehend texts with prose and graphics. If, as the findings indicate, strategic use of graphics is comparable to use of reading strategies, then possibly students may benefit from instruction about graphical use in ways similar to the ways they learn to use other reading strategies.

This instructional implication, for example, includes utilizing graphics *throughout* the reading process. Current instructional processes in science seem to involve using graphics solely as a pre-reading strategy. For example, *Once Upon a Life Science Book* (Wheeler-Toppen, 2010), published by the National Science Teachers Association, helps teachers in supporting students' science literacy, yet only promotes looking at graphics *before* reading:

> Reading Strategy: Previewing Diagrams and Illustrations. Tell students that in some books that they read, the pictures may be extras. In science writing, however, the pictures and diagrams often carry a lot of important information. Looking at the pictures and making predictions about what they mean before reading can help make the text easier to understand. (p. 55)

Although the report instructs teachers to tell students that graphics tend to show a lot of important information, it only instructs science teachers to teach the benefit of using graphics *before* reading a text. Instructional design should extend graphic use as a reading strategy that can be used *throughout* the reading process. Science instructors and instructional designers could perhaps instruct students about the use of graphics as a reading strategy in the same way they instruct readers how to use reading comprehension strategies. For example, teachers can embed use of graphics within instructional strategies such as reciprocal teaching, reflective questioning, modeling through think-alouds, question-answer relationship, and even reflective writing, among others (see Barton & Jordan, 2001).

This implication is also a possible bridge – a way to connect an apparent similarity between reading strategies and strategic use of graphics. For example, Afflerbach (2008) pointed out that "Teachers need to explain how to think to their students; that is, we need to model, describe, explain, and scaffold appropriate reading strategies for children." This type of instruction has also been described regarding students' knowledge and use of graphics, mostly in the context of science instruction (e.g., Lemke, 1990).

As mentioned in the theoretical perspective, there seems an imbalance in how we talk about, teach, and inform teachers to teach reading strategies versus how we talk, teach, and inform teachers to teach strategic use of graphics while reading. For example, even though the reading research field has rich and ongoing research on instructing readers in their use of reading comprehension strategies, the field is less abundant in supporting readers as they comprehend texts with prose *and graphics*. Instructing use of graphics as a possible way to perform reading strategies may also help to promote more balance.

SUMMARY OF IMPLICATIONS

In this chapter I discussed implications of the various findings with a focus on science curriculum design. The discussion of implications were embedded in each of the four thematic sections. I use Table 7.1 to summarize each implication and to organize them according to respective audiences of science curriculum design, such as design of science texts and science instruction.

Table 7.1. Summary of Implications

Implications by Area of Science Curriculum Design
Science Text Design
- Align text design and designer goals regarding engagement with graphics and access to science ideas graphics at various parts of the reading process.
- Support learning, engagement, and access by integrating design principles with findings. For example:
▪ Strategically place graphics to both support use before/during/after reading *and* proximate to complementary prose (e.g., apply graphics in line with prose).
▪ Utilize and make salient the features that can be both potentially interesting and relevant to the central science ideas in the text.
- Focus on accessibility of the instructional ideas for *both representations*, and incorporate a critical analysis of ways prose might help and/or hinder understanding of the graphics and vice versa.
- Use connective features in graphics:
▪ To mediate accessibility to science ideas.
▪ To scaffold students' transition from the ways they may tend to represent information to scientifically accepted representational formats.
Science Instructional Design (Teaching and Lessons)
- Consider both the joint use of graphics and reading comprehension strategies and the use of strategies on each representation individually.
- Instruct students about using graphics strategically with the same instructional practices as reading comprehension strategies (and possibly embed use of graphics with instruction on reading comprehension strategies):
▪ To promote various facets of meta-representational competence in reading.
▪ To direct instruction toward engaging with and accessing information from prose and graphics together.
- Incorporate instruction on how to compensate for poorly designed texts.
- Consider the types of conceptual information that should be taught or introduced before reading the texts (e.g., science ideas central to text and graphical signs/symbols used in graphics).
- Support instructors' critical awareness of everyday depictions in graphics as connective features (if features follow criteria).
- Identify and notify instructors of subtle and pronounced situations from prose, graphics and the integration of the two that might lead to difficulties in making sense of science texts.

LIMITATIONS

This study is encouraging and suggestive in many respects, but it has limitations. The first limitation to note is the small number of students in this study. Though the small number of students allow for more in-depth analyses about students' prose-graphic engagement, 20 students are not enough to generalize findings among the general population.

Another limitation to this study is my method of collecting data on when the students looked at the graphics while they read. I used students' think-aloud comments and students' reports of when they looked at graphics to discern the instances and frequency of their attention to the graphics. As I mention in the next section, other methods of collecting this type of data such as use of eye tracking tools may be helpful. Although even eye tracking methods may also not be ideal for exploratory studies (Rouet et al., 2008), as I mention in the next section, triangulation of data sources would be most beneficial for studies such as this.

The context and tasks I asked students to perform are also different from instructional environments and possibly "normal" reading conditions. For example, the prior knowledge questions, though allowing me to understand their prior knowledge, also foreshadowed the text content, which again may not usually occur before a student's normal reading process. Also, the read-aloud with think-aloud task, in making students stop reading and reflect on what they are thinking at certain instances that may be unnatural to them, may have also influenced more or less attention to and use of the graphics.

Another limitation of this study involves findings that are based on students' self-reports. There may be differences between what students actually did and what they say they did that I could not distinguish in this study. Therefore, as mentioned in the discussion, I could not discern whether students' reports were a reflection of their actual use of the graphics or a reflection of students being more or less metacognitive. However, with students' reports I *could* utilize their own thoughts and ideas about their prose-graphic engagement to an extent that could not be captured by other means.

The findings in this study are also based solely on two specific texts and the specific graphics within each text. Again the specificity of the text contexts can undermine the generalizability of the study, as readers' prose-graphic engagement can change according to such a variable.

FUTURE RESEARCH

Looking forward, I take the findings and implications of this study, as well as its limitations, into consideration. Although I have provided suggestions in describing ways students engage with prose and graphics while reading, these claims can become more definitive via other studies. The following questions can be asked in future research to make more definitive claims as well as to delve deeper into and gain more understanding of students' prose-graphic engagement when reading science texts:

Are the identified patterns with respect to integrated reading achievement and prior knowledge "characteristic" of all readers with similar individual characteristics? This first question is in response to the methods (and limitations) of this study. As an analytical and descriptive study, the goal was to identify patterns in students' prose-graphic engagement. The next step in this process is to focus on the patterns and characteristics I reported, and to increase the number of students to clarify and further understand the relationship between individual characteristics and their prose-graphic engagement. Triangulation of data via multiple tools such as eye tracking, log files, or other trace data, along with think-aloud protocols, may also benefit this research.

How might students' prose-graphic engagement compare when the reading context differs? By reading context I refer to the multiple science genres, and the media with which students read science texts with graphics. Further research on students' reading of other science genres beyond the science textbook is best supported by words of Goldman and Bisanz (2002):

> …in the digital information age, more and more scientific genres are being accessed by incidental audiences who do not participate in the community of scientists. If the public is to be able to take full advantage of this information personally and professionally, our educational system must begin to provide experiences that will enable the acquisition of processes for understanding, evaluating, and learning from more diverse genres of scientific texts. Making this type of scientific literacy a focal curricular emphasis of our educational system will require policy research, further study of the understanding and learning processes used by intended and incidental audiences for a wide range of genres, as

> well as studies of the forms of instruction that would make such scientific literacy achievable. (p. 44-45)

This study involved students' reading of science texts that were designed to be considerate to sixth graders, integrated with a science curriculum, and applied towards set instructional goals. However, these types of texts will be the minority throughout one's literate practices outside of the science classroom. Therefore, continuing similar studies around other genres can further develop our understanding of the ways readers read and make sense of science texts with graphics.

This study also asked students to "read aloud" print-based texts on a paper medium. The directions therefore confined the task to reading semi-linearly. Yet as Kress and Van Leeuwen (2006) note, "linear reading is gradually losing ground" (pg. 206). This is especially prominent via web-based texts, and even hypermedia contexts. One possible research focus, then, might identify and describe students' prose-graphic engagement in the context of reading web-based science texts.

How should we instruct readers to use graphics when reading science texts? This question relates to the findings about students using graphics as a reading strategy and students also using reading strategies on each representation individually. I suggest possibly incorporating graphics into practices that are already used to help readers learn reading strategies. However, to date I am unaware of research that embeds instruction of strategic graphic use with instruction of reading comprehension strategies. Research, however, has shown that providing methods for students that involve using strategies on each representation individually also supports their learning of the science text (e.g., Schlag & Ploetzner, 2011). However, what instruction might look like in incorporating both cognitive processing strategies has also yet to be explored.

How might we best support teachers in instructing readers on the use of graphics when reading science texts? I began to answer this question by identifying students' use of strategies on each representation individually and of graphical use as a reading strategy throughout the reading process. Instructing graphic use as a reading strategy holds promise, as Schroeder and colleagues (2011) reported that as teachers' beliefs that students should be taught clear strategies for learning from prose and graphics increased, the reported engagement increased for students.

Also, this question involves supporting teachers. To teachers, helping students learn to use reading strategies to support their comprehension of science texts can be intensive and time-consuming (Mokhtari & Reichard, 2002). The task may be more intensive when graphics are involved. Teachers must be aware of the role and function of the graphics in each text, as well as when these graphics might be best utilized (e.g., instructionally supportive opportunities). Teachers must then help students to become aware of why they are looking at a graphic, for example, towards the goal of connecting to prose, clarity, and/or better understanding. Research on how to support teachers in this endeavor can therefore involve science curriculum and text developers, possibly via educative curriculum materials (Davis & Krajcik, 2005), by highlighting to teachers purposes and uses, and instructionally supportive opportunities, to use graphics in reading the science texts.

How might using connective features support and prepare students in representational practices with graphics that lack such features? This question is based on the synthesis of the ways connective features can mediate students' learning of the science ideas in a graphic and support students' practices of using the representations (and the signs and symbols within a representation) as scientists use them. Studies specifically on such features will help to define their utility as well as positive and negative effects of their use. This question can be applied within the context of reading science texts, as well as the overall context of representations in instruction.

This also raises a related question about other possible affordances of graphics that can support and prepare students to apply scientifically accepted representational practices. For example, how can texts be designed to account for a reader's zone of proximal development (Schnotz & Kurschner, 2007)? Studying such adaptive instructional environments, whether they include connective features or not, can also support the overall goal of providing accessible information for students.

CONCLUSION

In conclusion, I return to my overarching goals – that is, to make science knowledge accessible to students, and to help students access that knowledge. In analyzing ways students engaged with the prose and graphics in two science texts, I have identified possible directions to achieve these goals. These directions involve supporting students to build upon their already existent meta-representational awareness, to use that knowledge by using graphics in strategic ways when reading science texts, and to support students' use of graphics through connective features. Paris and Winograd (1990) described that supporting students to become metacognitively knowledgeable and to use reading strategies is an opportunity to "provide students with knowledge and confidence that *enables* them to manage their own learning and *empowers* them to be inquisitive and zealous in their pursuits" (p. 22). In fact, in science, this opportunity goes one step further. Supporting students' meta-representational competence in their reading and supporting ways to help students transition from the "everyday" to the "scientific" are opportunities to help students access science in multiple arenas. This access then allows the students not only to manage their own learning, but also empowers them to make informed decisions that can affect their lives.

APPENDICES

APPENDIX A. THE TEXTS: *COOKING WITH OVENS* & *BITTER BLOCKERS*

Why should I think of molecules when choosing which oven to use to heat my food?

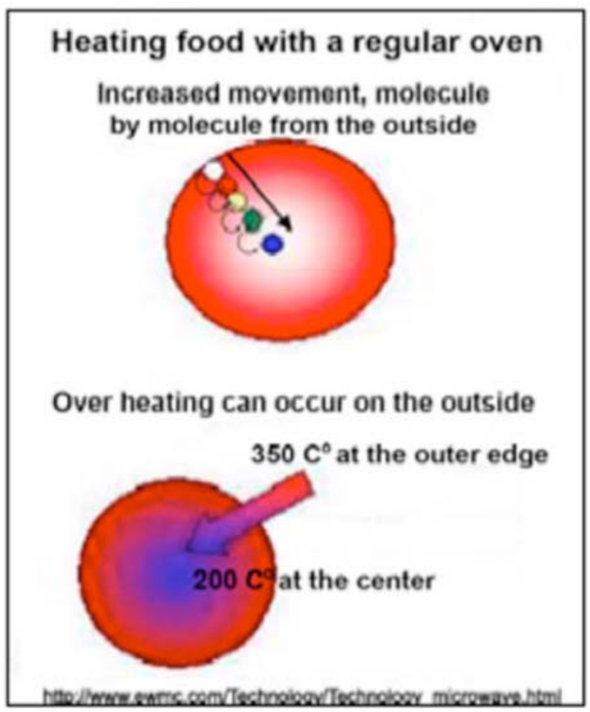
If you wanted to heat some pizza, you might use a microwave oven. Or, you might choose to heat your pizza by using a regular oven (which is also called a *conventional* oven). Both ovens can heat foods like pizza and hot chocolate. In both ovens, food gets warm as the molecules that make up the food move around faster. But the two kinds of ovens are different by the *way* they heat food. Each oven has a different way of making food molecules move around faster.

How do regular ovens heat food?

Regular ovens use hot air to heat food. When you turn on a regular oven, you can sometimes see coils in the oven get red-hot. The hot coils warm the air around them. The air warms up as the molecules in the air move around faster.

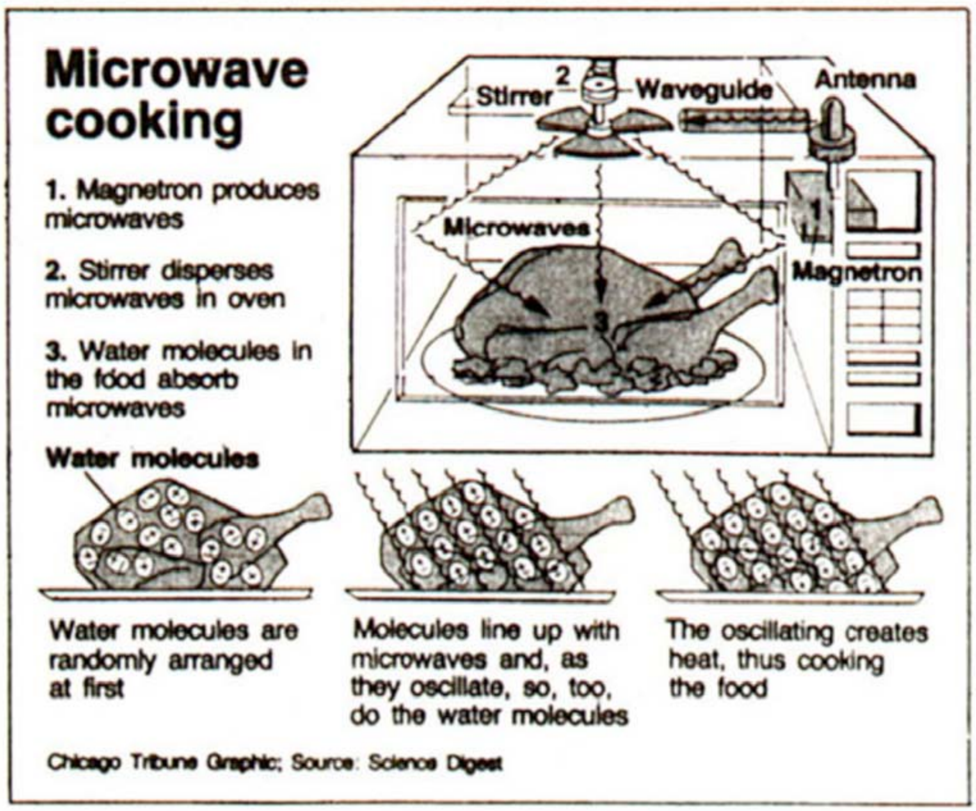
The hot air in the oven then heats the food. Fast-moving molecules in the air collide with the food molecules. The collisions make the food molecules jiggle faster. So the food molecules get more energy from the hot air molecules surrounding the food, and the food gets hotter.

You might have noticed that when you take pizza out of the oven too early, the inside of the pizza is still cold. It takes time for food to become warm all the way to the center. That is because in a regular oven, all of the food molecules don't move faster at once. The ones on the outside edges of the food start moving faster. Then they collide with the food molecules on the inside, making the inside food molecules move faster. It takes a long time because the food molecules are colliding one by one, from the edges of the food to its center.



How *microwave* ovens work
Microwave ovens are different because they do not use hot air to heat food. Instead, they work by heating food with a form of light that our eyes cannot detect, called *microwaves*. Microwaves can heat anything that has water in it. Nearly all of the foods you eat and drink have water in it, so microwaves can heat most foods, like hot chocolate and pizza.

When you turn on a microwave oven, a device in the oven makes microwaves. The microwaves reflect off the walls of the oven, and move in the oven in all directions. The microwaves also go through the food. As microwaves pass through the food, they are absorbed by water molecules in the food. The microwaves make the water molecules move back and forth faster (they move back and forth about a million times a second!). All of the faster-moving water molecules in the food then collide with the rest of the food molecules. That makes the *all* of the food molecules move faster. When the molecules in the food move faster, the food heats.



Microwave ovens tend to heat food faster than regular ovens. They are faster because the microwaves can make all of the water molecules in the food move faster, all at once. So you do not have to wait for each food molecule to move faster one by one, from the outside in, like regular ovens. Instead, the center part of the food can be heated at the same time that the outside of the food gets heated. That is why it takes a shorter time to heat pizza and hot chocolate in a microwave oven.

How can molecules make bitter foods taste better?

Think about eating a piece of sour candy. When people taste something sour, they often make funny faces. People might like sour candy because it also has a sweet, sugary taste to it. But they may not like foods that only have sour flavors - like lemons.

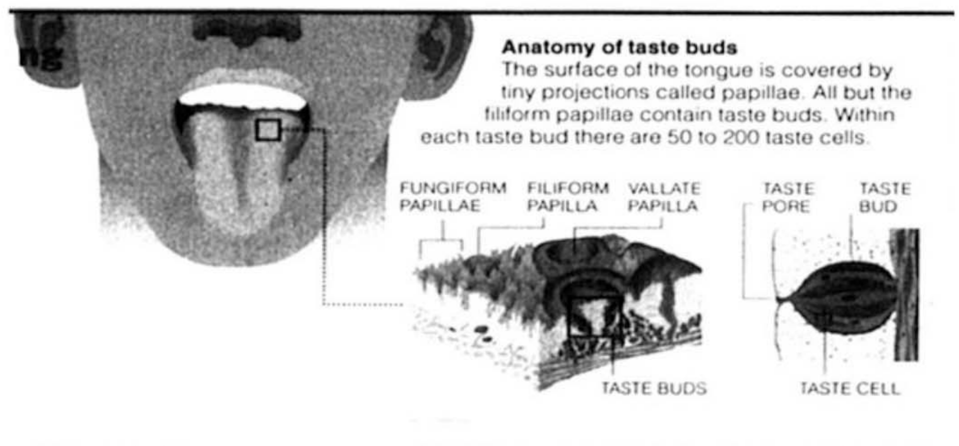
Some foods are also very bitter. Unsweetened grapefruit juice has a strong bitter flavor. Coffee also has a bitter flavor, which is why some people add milk, cream or sugar to their coffee. Many vegetables also have a bitter flavor. Milk chocolate is sweet, and dark chocolate is more bitter. Bitter flavors can also make medicine taste terrible. If you don't like the taste of grapefruit juice, vegetables, dark chocolate, or medicine, then it might be the bitter part that you don't like.

Many times, people won't eat foods with bitter flavors. In fact, companies that make foods with bitter flavors usually add a lot of sugar or salt to hide the bitterness. If enough sugar or salt is in the food, then people will notice the sweet and salty flavors, and not notice the bitter flavors. For many years, food scientists have been testing different ways to hide bitter flavors without adding salt or sugar. Scientists have now found different substances that can block the bitter taste in foods, drinks, and some medicines. These other substances are called "bitter-blockers." Bitter blockers don't hide bitter flavors like salt and sugar. Instead, bitter-blockers stop the tongue from detecting bitter flavors.

How do bitter blockers work?

Scientists who study how people taste once thought that a specific place on the tongue detects each flavor. For example, the back right part of your tongue might detect bitter. The front tip of your tongue might detect sour. However, scientists changed their models of how people taste. They now know that you can taste each flavor on any part of your tongue.

Scientists also know that the tongue is covered with tiny pinkish-red "mounds" (called papillae). These mounds are where the taste buds are. Taste buds help to tell what flavor the food is. When you chew, the saliva in your mouth (your spit) breaks food up, into single molecules that make up the food. The food molecules touch the taste buds. The taste buds then send a signal to your brain that tells what flavor the molecule tastes like.



When a bitter blocker molecule is in the food, it blocks the bitter-tasting molecules from touching the bitter-detecting taste buds. The bitter-tasting molecules are still there. But if the bitter-tasting molecules do not touch the taste buds, then the brain does not get a signal that they are there. If the brain doesn't get a signal, then you can't taste the bitter flavors.

Scientists have found that humans have at least 30 different types of bitter detectors on their tongues. They haven't found a substance that can stop *all* of the bitter flavors from being detected. But scientists have found 20 different types of bitter blockers. One of the bitter-blockers is called AMP (which is short for its chemical name, adenosine 5'-monophosphate). People have tested whether bitter blockers like AMP work. People have tasted grapefruit juice without AMP (the bitter blocker), and thought the juice tasted "nasty." Then they tasted the same grapefruit juice with AMP. They thought it tasted "tangy," but not bad like the first juice.

Accounting For Taste

New compounds may make it possible to hide the taste of bitter foods without adding sugar or salt, the usual methods for making bitter foods more palatable. Here is how these compounds, called bitter blockers, work.

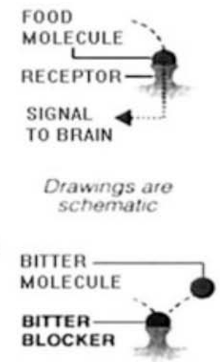
Sources: Atlas of Human Anatomy, Linguagen

How we taste

Food molecules mixed with saliva contact taste cells through taste cell pores. Taste receptors in the cells then send signals to the brain to interpret taste.

Blocking bitterness

Bitter blockers prevent the receptors from capturing bitter molecules, which have unique shapes. The blockers are swallowed with the rest of the food.

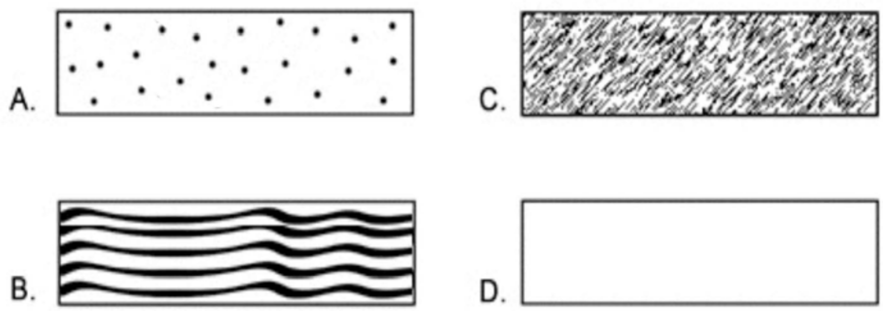


The New York Times

APPENDIX B. UNIT PRETEST ITEMS

Multiple Choice Items

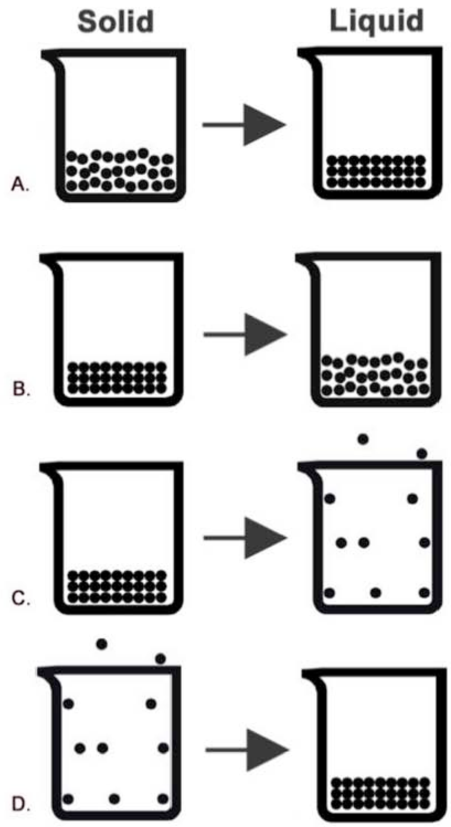
1. ***Below are four possible models of a gas.* Which model would a scientist use to explain how water vapor condenses to a liquid?**



4. If you could use a powerful microscope to see the particles in a gas, what would you see between the particles in a gas?
   A. More particles
   B. Air
   C. Empty space
   D. Liquid

5. When a sample of liquid water is heated it expands. What happens to the molecules?
   A. The number of molecules increases, and the space between them gets bigger.
   B. The molecules get bigger, and the space between them increases.
   C. The molecules stay the same size, and the space between them increases.
   D. The number of molecules decreases, and the space between them gets bigger.

8. In the following models each circle represents a wax molecule. Which model best represents what happens when a solid wax melts into liquid wax?

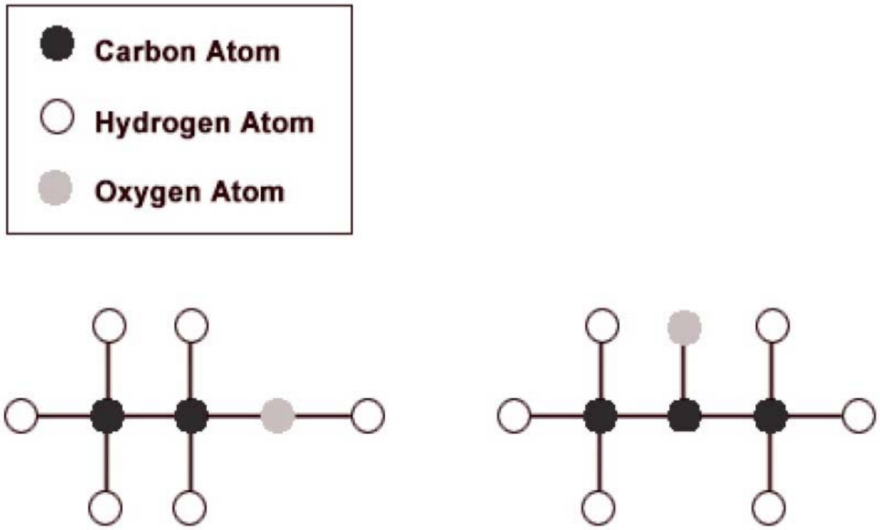


9. When a substance changes from a liquid to a solid, which of the following is true?

A. The molecules get colder.
B. The molecules of the solid move faster.
C. The molecules of the substance change from soft to hard.
D. The molecules move more slowly.
E. No, they are not matter because they grow on birds.

12. If a container of water is sealed and kept at a constant temperature, then what can you say about the motion of the water molecules?

A. All the water molecules will continue moving.
B. All the water molecules will slow down and eventually stop.
C. All the water molecules will slow down a little bit but not stop.
D. All the water molecules will speed up a little bit



13. ***Use the models above to answer this question*. Both of these molecules are composed of oxygen atoms, carbon atoms, and hydrogen atoms. Are they molecules of the same substance?**

A. Yes, they are the same substance because they are made of the same type of atoms.

B. No, they are different substances because the atoms have different arrangements.

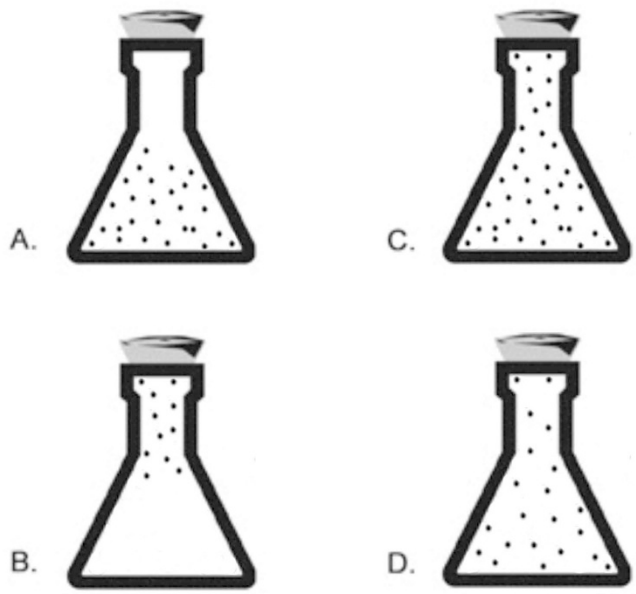
C. Yes, they are the same substance because they are both liquids.

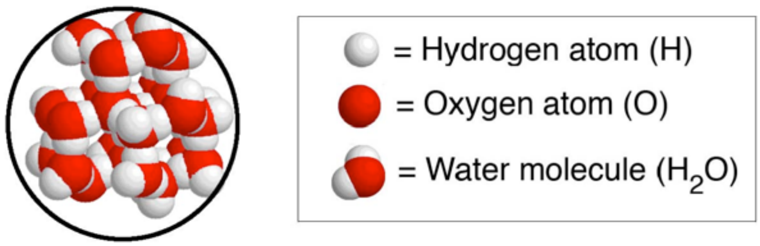
D. No, they are different substances because they have different masses.

Use this model to answer question 15

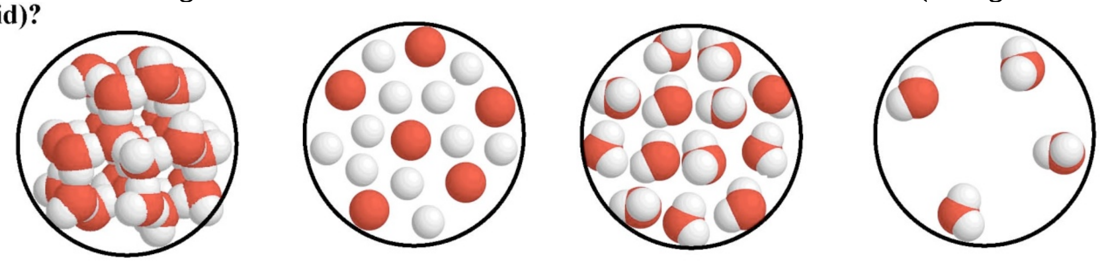
Here is a model of a gas in a flask.

15. Imagine that some of the gas in the flask was removed. Which one of the following models best represents the gas that remains in the flask?





16. A diagram representing water molecules in the solid phase (ice) is shown above. Which of these diagrams best shows what water would look like after it melts (changes to a liquid)?



A. B. C. D.

17. Consider two samples of water in two phases. The first is liquid water at 24°C, and the second is gaseous water at 100°C. The water molecules in the liquid phase __________ the water molecules in the gaseous phase.

A. move faster than
B. move slower than
C. move at the same speed as
D. travel in the same direction as

Written-response questions

1. *Bill and Shauna wondered if they could smell an air freshener faster in a cold room or a warm room. They decided to do an experiment: They made the room cold ($50^{o}F$), plugged an air freshener in, and measured the time it takes for the smell to reach the door. The next day, they made the same room hot ($85^{o}F$), plugged in a new air freshener, and again measured the time it takes for the smell to reach the door.*

A. What do you think would be the results of Bill and Shauna's experiment? Circle one of the following options:

1. The smell reaches the door at the same time in both temperatures
2. The smell reaches the door faster at $85^{o}F$
3. The smell reaches the door faster at $50^{o}F$

B. Second, draw models that can help you explain your choice in part A. (Your models should show how the odors reach the door at lower temperatures and higher temperatures) Make sure to label the different parts of your model Key:

C. Use your model to explain why you chose your answer in part A. Your statement should show how the odors reach the door at lower and higher temperatures.

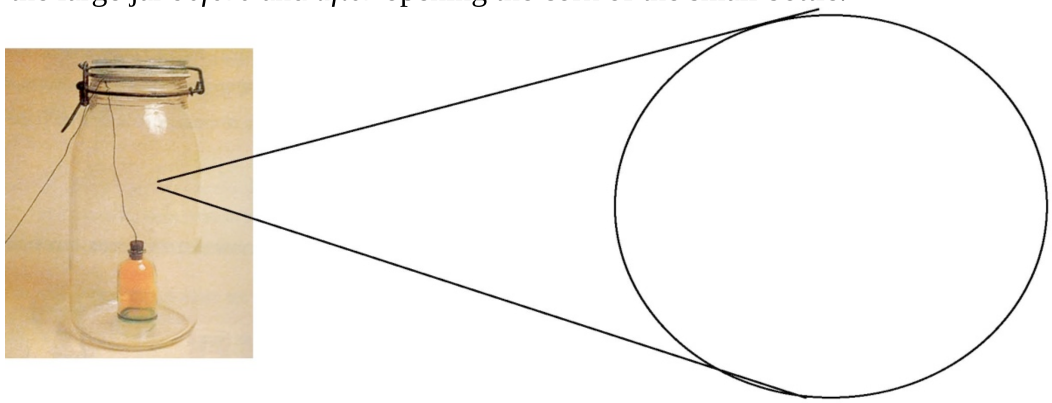
2. *Shayna had a small bottle of Bromine gas. The bottle was closed with a cork. She tied a string to the cork, and then placed the bottle inside a larger jar. The large jar had air in it. She sealed the large jar shut. (See Figure 1.) Next, Shayna opened the small bottle by pulling the string connected to the cork. Figure 2 shows what happened after the cork of the small bottle was opened.*

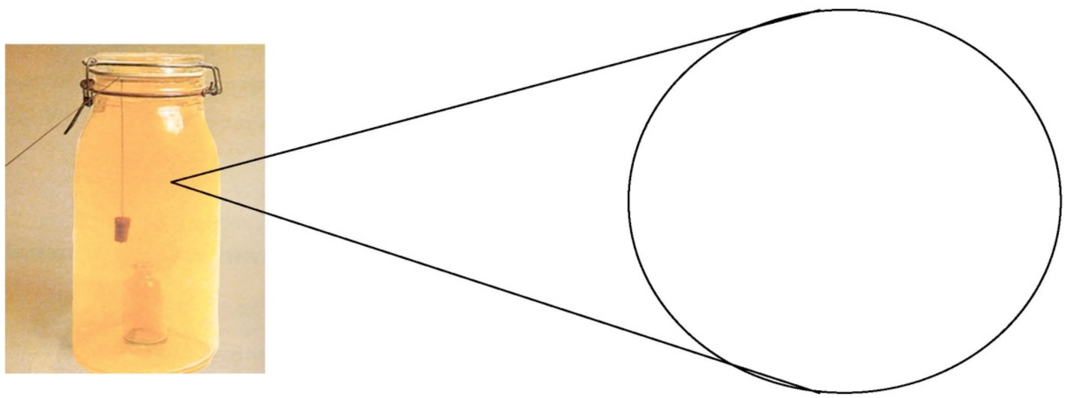
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Figure 1

Figure 2

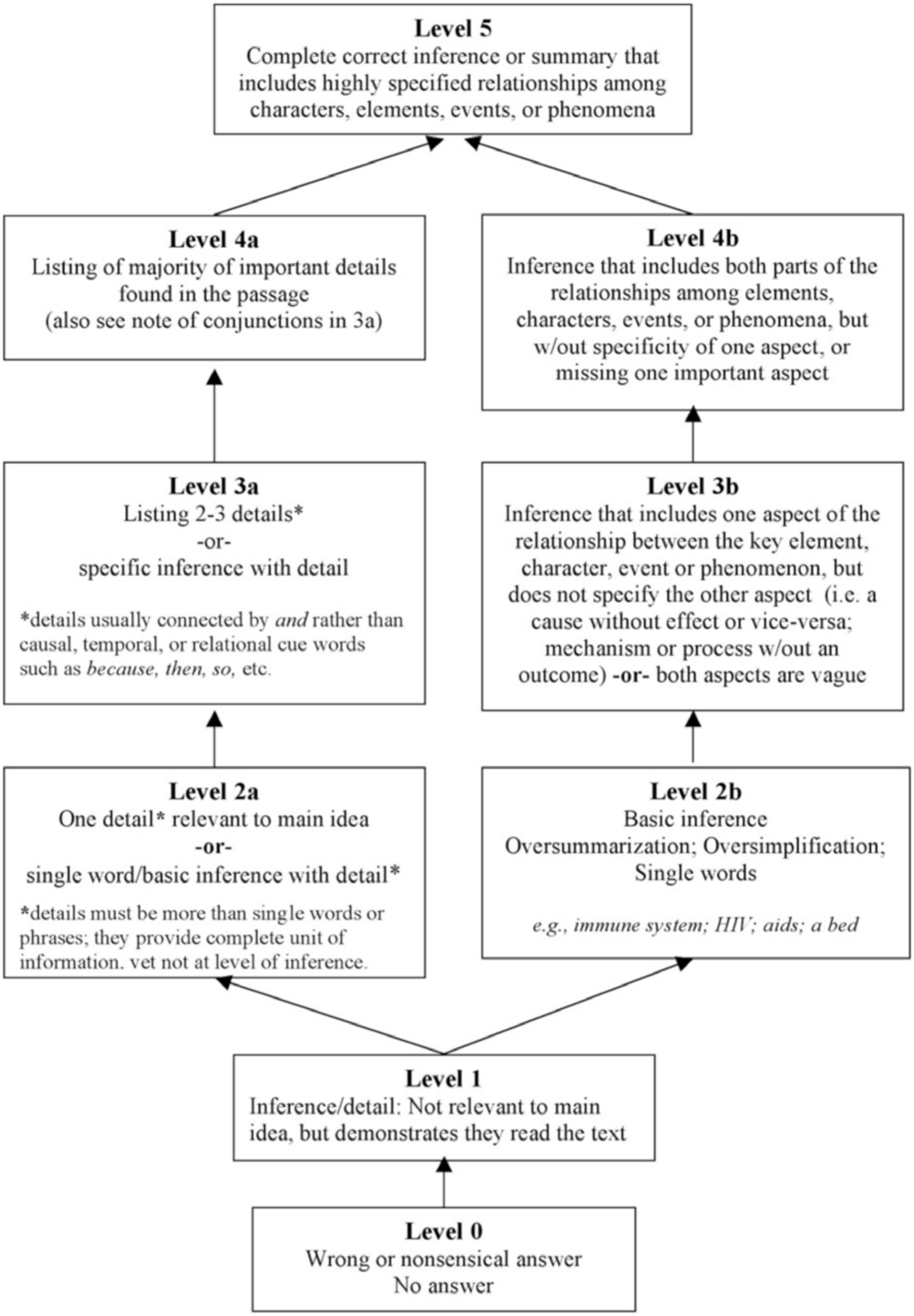
A. Imagine that you have a very powerful microscope that would allow you to zoom into a tiny spot in the large jar. In the circles ***below***, draw a picture of what you think is in the large jar *before* and *after* opening the cork of the small bottle.





B. Use your models to write a statement about what happened to the bromine, when the cork of the small bottle was opened

APPENDIX C. 2007 SARA MAIN IDEA RUBRIC



APPENDIX D. PART OF INTERVIEW EACH STUDENT PARTICIPATED WITH FIRST

Pre-Interview Reading Group and Students	Part 1 (Cooking with Ovens)	Part 2 (Bitter Blockers)
Low		
Blair	X	
Fran	X	
Casey		X
Garnet		X
Dana	X	
Medium – Low		
Haiden		X
Jessie	X	
Layne		X
Macy		X
Kris	X	
Medium – High		
Patel	X	
Quinn		X
Rene	X	
Neci		X
Sam		X
High		
Vaan	X	
Terri		X
Xipil		X
Walei	X	
Zavit	X	

APPENDIX E. INTERVIEW PROTOCOL

Cooking with Ovens Prior Knowledge Questions

1. Tell me about microwaves.
    a. What about cooking with microwave ovens?
    b. What about cooking with other ovens?

2. How do microwaves heat food?

3. How are microwave ovens different from regular ovens?

4. Tell me about molecules [if this text is 1st]? –or- Earlier you told me about molecules. Is there anything you want to add about molecules? [if this text is 2nd]

    a. Where are molecules?
    b. Give me an example of a molecule

5. What might molecules have to do with heating food [if this text is 1st]?

[*show text to students, then ask next questions*]

6. Given that the title of the passage is -----, and it includes ideas like ovens and molecules, what do you think the passage will be about? *If the student restates the title of the passage, ask:* "What about ____?" or "Tell me more about ____"

7. On a scale of 1 to 5, how interested are you in reading this to find out more about heating food?

    a. Why do you choose a --?
    b. What do you think might be interesting about this text?

Student Reads

Now I'd like you to read this out loud. See these cloud icons? Those are places where I'd like you to think-aloud (tell me what you're thinking and doing). You can also tell me what you're thinking at any time while you read. And remember, if you are silent for a while, I might ask what you're thinking, what you're doing, or what you're looking at.

Cooking with Ovens Retelling

"I'd like you to retell this passage that you just read, but pretend that you're talking to someone you know who is older than you, like a friend in 8th grade, an older brother or sister, or even your parents or grandparents."

Cooking with Ovens Comprehension Questions

1. What is a microwave?

2. How do microwave ovens work?

3. What happens to molecules in food when the food gets heated and cooked?

4. Why might people use microwave ovens instead of regular ovens?

5. What makes microwave ovens heat things differently than regular ovens?

[Go to Associated Interest/Metacognitive Questions]

Bitter Blockers Prior Knowledge Questions

1. How does our sense of taste work?

    a. How do people taste different flavors?

2. What foods taste bitter to you? *(if student pauses, can ask, "if someone were to say, 'that tastes bitter'" what does that mean?)*

3. Tell me about taste buds?

    a. How do they help you taste?

4. Tell me about molecules [if this text is 1st]? –or- Earlier you told me about molecules. Is there anything you want to add or change? [if this text is 2nd]

    a. Where are molecules?
    b. Give me an example of a molecule

5. What might molecules have to do with bitter tasting foods?

[*show text to students, then ask next questions*]

6. Given that the title of the passage is -----, and it includes ideas like bitter foods and molecules, what do you think the passage will be about? If the student restates the title of the passage, ask: "What about ____?" or "Tell me more about ____"

7. On a scale of 1 to 5, how interested are you in reading this to find out more about making bitter foods taste better?

    a. Why choose a --?
    b. What do you think might be interesting about this text?

Student Reads

Now I'd like you to read this out loud. See these cloud icons? Those are places where I'd like you to think-aloud (tell me what you're thinking and doing). You can also tell me what you're thinking at any time while you read.

Bitter Blockers Retelling

"I'd like you to retell this passage that you just read, but pretend that you're talking to someone you know who is older than you, like a friend in 8th grade, an older brother or sister, or even your parents or grandparents."

Bitter Blockers Comprehension Questions

1. Why do companies add salt and sugar to food?

2. What are bitter blockers?

3. How do bitter blockers work?

4. Why do scientists study bitter blockers?

5. How can scientists tell if bitter blockers really do work?

Interest & Metacognition Questions 1st Text

- What is the goal of this passage you read? [pointing to prose]

- I'm curious, Do you usually look at the diagrams when you're reading?
  - When do you tend to look at diagrams when reading in general?
  - When did you look at the diagram?
  - Why did you look at the diagram? –or- What made you look at it?

- Can you tell me a little bit about the diagrams in the passage? [point to graphics]

- What do you think is the goal of the diagram?

- Were there any times while you read that you connected the information from the diagram with the information you were reading?

- How does the diagram relate to the words you read?

- How interested were you when reading this passage?
  - What made it (interesting/not interesting/# - if can compare to prior, do so)

- Can you show me a part that made it interesting/not interesting?
  - Why did you like this part?
  - Are there other sections you liked?

- How interested were you in looking at the diagram?
  - What parts of the diagram did you like? Why?

- If you read something in science and it doesn't make sense, or is confusing, what do you do?
  - Were any *parts* in this passage confusing or doesn't make sense?
    - What made this part confusing?
  - *if the s points to diagram* –
    - how did you make sense of it?
    - did you use the passage to help you make sense of it?
  - *if points to section* –
    - how did you make sense of it?
    - did you use anything in the diagrams to help you make sense of it?

- When you come to a new science word that you don't know, what do you do to make sense of the word?
  - [ask only if s did not discuss words above]: Were there any *words* in this passage that you had a hard time reading, or that you didn't understand?
    - What did you do? What do you think that word meant?

- Say you had to help someone in your science class to read and understand these texts. What ways would you help other students in your class understand the science text?[2]

- Let's go back to the diagrams -- How useful was each diagram?
  - What made it useful? –or– why isn't it useful to you?
  - Were there any parts of the diagram that you didn't look at when reading?
    - Tell me more about (why you didn't look at it)…
  - Were there any parts of the diagram that you didn't understand?
    - Tell me more about (the part)…

- What ways did information from diagram(s) help you to understand what you were reading?

- What ways did the information you read help you to understand the diagram(s)?

- What type of graphic would you put here to help someone understand what they're reading?
  - What type of graphic would you put here to get someone to be interested in the reading?

Interest & Metacognition Questions 2nd Text

- What is the goal of this passage you read? [pointing to prose]

- Earlier I asked you about when you look at the diagrams. When did you look at the diagram?
    - Why did you look at the diagram? –or- What made you look at it?

- Can you tell me a little bit about the diagrams in the passage? [point to graphics]

- What do you think is the goal of the diagram?

- Were there any times while you read that you connected the information from the diagram with the information you were reading?

- How does the diagram relate to the words you read?

- How interested were you when reading this passage?
    - What made it (interesting/not interesting/# - if can compare to prior, do so)

- Can you show me a part that made it interesting/not interesting?
    - Why did you like this part?
    - Are there other sections you liked?

- How interested were you in looking at the diagram?
    - What parts of the diagram did you like? Why?

- Were any *parts* in this passage confusing or doesn't make sense?
    - What made this part confusing?
    - *if the s points to diagram* –
        - how did you make sense of it?
        - did you use the passage to help you make sense of it?
    - *if points to section* –
        - how did you make sense of it?
        - did you use anything in the diagrams to help you make sense of it?

- [ask only if s did not discuss words above]: Were there any *words* in this passage that you had a hard time reading, or that you didn't understand?
        - What did you do to make sense of the word?
        - What do you think that word meant?

- Say you had to help someone in your science class to read and understand these texts. What ways would you help other students in your class understand this science text?[2]

- How useful was each diagram?
  - What made it useful? –or– why isn't it useful to you?
  - Were there any parts of the diagram that you didn't look at when reading?
    - Tell me more about (why you didn't look at it)…
  - Were there any parts of the diagram that you didn't understand?
    - Tell me more about (the part)…

- What ways did information from diagram(s) help you to understand what you were reading?

- What ways did the information you read help you to understand the diagram(s)?

- What type of graphic would you put here to help someone understand what they're reading?
  - What type of graphic would you put here to get someone to be interested in the reading?

- tell me in these two passages which diagrams were more helpful and why is this helpful to your reading?

Appendix F. Comprehension Questions Rubrics

Cooking with Ovens Rubric

1. What is a microwave?

Code	Criteria	Notes / examples
0	no response -or- response does not answer question or is incorrect -and/or- not from text	
1	one detail that does not fully answer question -or- a general inference (eg. "heats food")	- uses light (but not specific what type); - what MW oven looks like; etc. - it heats your food / warm things up / get things hot
2	2 or more detail yet fragments or incomplete -or- general description of either an oven or a microwave	- a heating device…uses microwaves to heat food…[comes out of little light bulb…keeps taking out water molecules until they're all gone]
3	2 or more detail complete or more specific description – less fragmented	- definition of microwave in text ("a form of light our eyes cannot detect") or similar statement - "A microwave is a type of oven that doesn't use, um, light to heat the food. It uses microwave light or just microwaves."

2. How do microwave ovens work?

Note – can use students' responses to Q1 to help answer to Q2 (but not vice-versa)[32]

Code	Criteria	Notes / examples
0	no response -or- response does not answer question or is incorrect -and/or- not from text	- mw oven has water molecules that go around the mw... it heat the mw… has a light bulb… has silver parts surrounding it… metal surrounding to heat the food. - use a signal that tells mw how to work… work by little light…puts out rays until keep hitting…[all h2o molecules in food is gone
1	1-2 details that does not fully answer question -or- a general inferences	- uses light / electricity / microwaves - uses microwaves to heat food
2	3 or more details yet fragments or incomplete (includes 3 of the 5 steps to the process below right) *details must be correct to count	- by microwaves… something making a microwave… going through the food then h2o molecules [heat up] the rest of the molecules so food heats up
3	4 or more details; more complete (includes 4 of the 5 steps to the process below right) *details must be correct to count	- it gives off mws… water molecules… then move faster… collide w/ other food molecules which then move… - something in oven makes microwaves… microwaves reflect off walls..heat food… mws go thru food… when all molecules move they collide…energy to heat
4	5 or more correct details; complete (Includes the 5 to the right – brackets not necessary)	1. *microwave* made/used/given off 2. microwave/light bounces around/goes thru food 3. microwave/light hit/absorbed by/align [food/ molecules] 4. [microwave/light causes] molecules move faster 5. [faster molecules hit/collide/make other food molecules move faster] make food heat

3. What happens to molecules in food when the food gets heated and cooked?

Molecules move faster (0=wrong; 1=correct but not "faster"; 2= "faster")

Eg: "molecules move really fast" is scored a 1; "molecules absorb microwaves" is also a 1

4. Why might people use microwave ovens instead of regular ovens?

To cook food faster (shorter time)

(0=wrong; 1=close & correct, don't say above; 2=say above)

if only say "faster" and extra information is not correct (ie heating molecules) – give a 1. If other information implies timing – give a 2. If no other info except Q3 response, give

[32] I allow this for the following reasons: first, a student might answer Q1 as if describing microwave *ovens* and therefore might provide some mechanism, then not include it in Q2 because s/he already stated it and wouldn't repeat the response. However, Q2 cannot be used to answer Q1.

5. What makes microwave ovens heat things differently than regular ovens?
[note: details must be (1) correct and (2) be a difference from regular ovens (contrasted detail about regular oven doesn't need to be stated) in order to count] ~ details are bracketed and italicized

Code	Criteria	Notes / examples
0	no response -or- response does not answer question or is incorrect -and/or- not from text	- no difference
1	1-2 correct details: fragmented -or- a general inference that does not fully answer question -any # details that do not fully answer the question but are true about difference btwn the ovens *or* 1 detail that is not enough information (fragmented/incomplete) but would count for other codes	- microwaves cook fast - [*uses light*] instead ~~of heat~~ - a microwave [*has a fan*] in it which has the heat in [and?] [*water molecules move around*]
2	2 or more details; not fragmented, but not complete.	- microwave ovens [*use micro-waves/light*] while other ovens [*heat up a coil*] - [*uses light*;] other *ovens* [*use…warm air*]
3	3 or more details; more complete but not fully. – details about each oven may be included, yet the contrast is not apparent	- "They [use *light microwaves*] [*to enter the food*] and [*it gets absorbed by*] [*water molecules*]…Regular ovens … and [if the food *isn't in long enough*, it *doesn't heat up the center*, but it *heats around the center*]." - "um, *it* [*uses light*,] heat, [*and water*], and conventional ovens only [*use … warm air*]"
4	3 or more details; more complete - must include how [food/water] molecules are affected; can - includes source (microwaves versus hot air)	- microwaves make [*molecules in food*] [*move fast at once*]; regular ovens [molecules move faster *one by one]*

<u>*Bitter Blockers* Rubric</u>

1. Why do companies add salt and sugar to food?
To hide the bitter taste [a person still tastes the bitter, but doesn't notice]

Code	**Criteria**	**Exemplar**
0	no response -or- response does not answer question or is incorrect -and/or- not from text	Some possible responses: - "block"
1	Mix of correct and incorrect OR (Comments might include "block" as bitter blockers do, and2wswzqaSWAQ talk about hiding)	- "to stop it from tasting so bitter" - "so consumers *won't taste bitter*" - "…to make it not taste as bitter so that the bitterness doesn't get to the bitter taste buds"
2	Correct	- "cover up the bitter taste" - "make it taste *not as* bitter" / make it taste better - "people will…not notice the bitter flavors"

2. What are bitter blockers? Here we're looking for what they are and what they do (we are not separating the two)

Code	**Criteria**	**Exemplar**
0	no response -or- response does not answer question or is incorrect -and/or- not from text	
1	one detail that does not fully answer question -or- a general inference/description	- *things you put on or in bitter food* to make it not bitter
2	>1 detail yet fragments or incomplete -or- general description; might include either what it is or what it does (below) Details must be correct to count	- it blocks the tongue from tasting the bitterness in food
3	> 1 details complete or more specific description – not fragmented: (must include one of below) if includes both of below, then scored a 3: - <u>what they are</u> (substances, chemicals, things put in food, name of one, etc.) - <u>what they do</u> (bock bitter [tastes /flavors / molecules] from touching taste buds)	- *blocks bitter tasting molecules from touching taste buds* - it covers …your bitter-tasting buds…

3. How do bitter blockers work? (can include response to Q2) Note: Here we're looking for the *mechanism* with which bitter blockers work: How they block bitter flavors – and if students break it down at the molecular level.

Code	Criteria	Exemplar
0	no response -or- response does not answer question or is incorrect -and/or- not from text	
1	1-2 details that does not fully answer question -or- a general inferences	- it blocks the tongue from tasting the bitterness in food (Q2)…try to block the bitterness in the food you're eating
2	>2 detail yet fragments or incomplete or general (includes 3 of the 6 steps to the process below) *details must be correct to count	- things you put in or on bitter food make it not bitter (Q2)… putting it in food to make it harder for the bitter taste to get to your bitter tasting tb… tb don't sense the bitter… don't send message to brain.(Q3) - don't allow the bitterness molecule to touch the taste buds' papillae…so it blocks it so there's no message sent to the brain that it's bitter…(Q2)… stop bitterness flavor from touching mounds of taste buds on tongue…blocks bitterness so brain doesn't get a signal
3	>3 details; more complete (includes 4 of the 6 steps to the process below) *details must be correct to count	- covers your papilaes…the bitter taste cant hit because the bitter-blockers block the bitter form coming onto taste bud…if can't get to tb, can't send a signal to brain, you can't taste it (Q3) - blocks bitter tasting molecules from touching taste buds (Q2)…if the bitter tasting molecules never touch your taste buds, it never sends a signal to brain telling you that it tastes bitter…you can 't taste it (Q3)
4	>4 correct details; complete (Includes 5 of the 6 below – brackets not necessary)	
5	>5 correct details; complete (Includes the 6 below – brackets not necessary) Complete description and specific	1. [bitter blocker/tasting] molecules 2. Cover taste buds / blocks bitter 3. Taste buds/bitter thing don't touch/interact 4. Bitter tasting thing is still there 5. Taste buds do not sense the bitter taste/molecule / Taste buds do not send a message to the brain / Tongue doesn't sense 6. Then you can't taste the bitter flavor

4. Why do scientists study bitter blockers?
Note – students response to Q5 can also be used to help their response to this Q

Code	Criteria	Example
0	no response -or- response does not answer question or is incorrect -and/or- not from text	- want to know how many taste buds you have - how many bitter blockers you have on your tongue
1	General – associated w/ role of bitter blockers	- to make food taste less bitter
2	Includes aspect of improving current practices (i.e. using salt/sugar) - or- includes continuing & building on knowledge	- *more efficient way* so you don't taste bitterness flavor…so companies don't have to add…sugar.. - to enhance tastes in other ways besides salt and sugar --------------------- - to find out how to make more - "they want to know more about it" - how to make a bb that can stop all bitter tasting - figure out more ways to block all 30 - "so people can have better tasting food…don't taste bitter"
3	Both of above	

6. How can scientists tell if bitter blockers really do work?

Code	Criteria
0	No answer or totally incorrect
1	Say experiment/test; but no other info –or- mention tasting, but not complete
2	Explain experiment that is mentioned in text more complete

Note: - incorrect statements will be ignored in the scoring, but noted/listed in the overall assessment of students' comprehension (this is so a student cannot be penalized for saying incorrect statement multiple times in their responses to all questions)

Determining Comprehension:

Rescore each question to 0-2 (based on color coding) (highest score = 10):
Independent = if at independent of 3-5 questions; instructional at 1-2 = 80% and up
Instructional = if at independent for 1 question; instructional for 4 questions = >50%
50% = if instructional for all 5 questions; or instructional for 3 questions, plus 1 independent and 1 frustration. Use recall to determine if instructional or frustration level.

APPENDIX G. LEVELS OF PRIOR KNOWLEDGE IDEAS

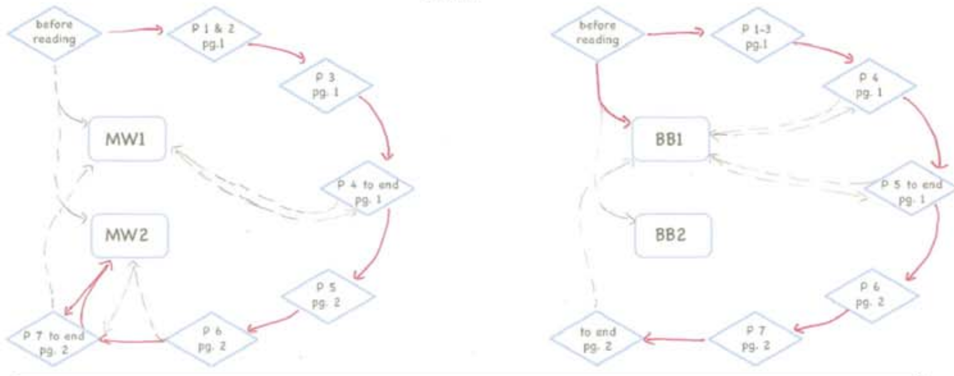
Molecules: Level and Ideas	# students
In process level (6-8:beginning and middle)	
Description Molecule – size: really small / tiny; cannot see molecules; need a microscope / need a super powerful microscope to see them	14
Description Molecule – variety/make up characteristics: *different types* of molecules exist	3
Kinetic Molecular Theory: movement/spacing molecules [only]	3
What molecules make up – specific things: molecules are in/make up: specific solids and/or places [eg: room, body, desk, solids]; specific gases [eg: air, gases]; specific liquids [eg: water, shampoo, liquids]	15
What molecules make up – specific things: molecules are in/make up food or flavors/tastes	11
Examples: names a phase or general name (food molecules; gas molecules); or substance (water molecules)	11
Description Molecule – other names: (eg: molecules are chemicals / particles)	2
Where molecules are – general: molecules are around the room; molecules are everywhere (not completely correct)	13
What molecules make up – general: molecules in everything (not completely correct); make up stuff; [create/make up] everything / every object / all matter (not completely correct)	12
What molecules make up – amount: [a lot / hundreds of billions] [of molecules] in something	2
Above level (end 6-8; 9-12 & Unit LS2&3)	
Kinetic Molecular Theory: molecules change [movement/spacing] according to temp.	3
Description Molecule – variety/make up characteristics: made up of atoms / a group of atoms	6
Description Molecule – variety/make up characteristics: *certain molecules* consist of *different atoms* / different arrangement atoms	4
Description Molecule – variety/make up characteristics: there's things orbiting around it (molecule) / other particles stick onto it	2
Kinetic Molecular Theory: molecules can evaporate (into air)	2
Kinetic Molecular Theory: spacing molecules relative to phases [eg: make objects harder]	1
What molecules make up – differences with atoms: some stuff made of molecules; some stuff made of atoms	1
What molecules make up – varied substances: *different types* of molecules make up *different types* of objects	2
Examples: uses chemical formula	5
Misconception	
molecules are in light / light molecules / microwaves	2
more/less molecules make up a taste/flavor; molecules [carry] taste	4
molecules get hot/cold / heat up; heat molecules exist	6
molecules *get* in food; are *on* food	5
molecules heat food / microwave / air	6

Microwaves & Ovens: Level and Ideas	# Students
At level (K-5)	
microwaves [heat up/cook] [food/things] (states this before probe in Q1)	18
Type of light microwave ovens use - general: microwaves use [some type of] light	8
Action light in microwave : microwave - light shines in all directions; bounces off in all directions; light keeps hitting food	3
Light-food interaction: food absorbs light / microwaves	3
Mechanism heating for regular ovens: regular ovens inside get hot / heat up	8
microwaves use electricity / electricity involved	5
Mechanism heating for regular ovens: regular ovens use/have fire or gas	5
In process level (6-8:beginning and middle)	
Type of light microwave ovens use – more specific: microwave ovens use/send out [*light rays/waves]* or *micro-waves*	6
Characteristics micro/light-waves: you cannot see micro-waves / light	4
result of light-food interaction: absorption of light makes food hotter	3
result of light-food interaction: light/energy heats food/things	3
Mechanism heating for regular ovens: regular ovens do not use light	3
Characteristics micro/light-waves - not fully correct/complete: micro-waves are fast/slow; short/long; wobbly; "like the kind you hear"	3
Characteristics micro/light-waves: light/waves have energy	2
Above level (end 6-8; 9-12 & Unit LS2&3)	
Light-food interaction - more specific: molecules absorb light (G=interact/react with microwaves)	3
Light-food interaction *[interaction/reaction]* of molecules with light results in *heating food*	1
Heating mechanism: energy *transferred* to food and turned into heat	3
misconceptions	
microwaves - light / heat from light bulb	8
microwaves - some type of heat in it / gives off heat (may refer to heat lamps)	9
micro-waves/light is infrared or ultraviolet	5

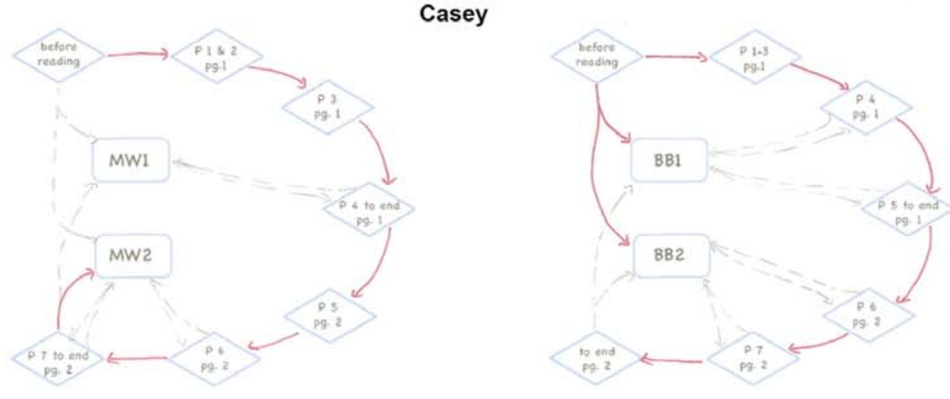
Tasting & Taste Buds: Level and Ideas	# Students
At level (K-5)	
mentions taste buds before probe [G & F did not say taste buds but said sensors and cells respectively]	18
Taste Buds Are (types of descriptions about them): on tongue / specific parts of tongue [link btwn taste bud and tongue]	14
Taste Buds Are (types of descriptions about them): size: tiny / really small	7
Taste Buds Are (types of descriptions about them): dots (description of what are) / bumpy	5
Taste Buds Are (types of descriptions about them): different taste buds exist	7
mechanism of tasting – detection: *taste* flavors / different types of stuff / tell what flavor	8
mechanism of tasting – result of detection: [tell/send/carry/track] [information /messages/signal /sense] to brain	6
mechanism of tasting – response of brain: brain responds to sent signal / brain tells you if you like it or not / makes you taste the flavor	5
Taste Buds Are (types of descriptions about them): a lot /thousands of taste buds on tongue	4
mechanism of tasting: ingesting / taking in food: flavor goes around mouth	1
In process level (6-8:beginning and middle)	
Taste Buds Are (types of descriptions about them): detectors / receptors / sensors / sensitive to taste	5
mechanism of tasting: ingesting / taking in food: when you eat, you eat molecules	1
mechanism of tasting – detection: food interacts with/moves on taste buds / taste buds hit food	2
mechanism of tasting – detection: taste buds [recognize/detect/catch/take information] [*flavors/food]*	5
mechanism of tasting – detection: *different* taste buds detect different flavors	7
mechanism of tasting – detection: different molecules give off different tastes / certain molecules are in bitter foods	5
Above level (end 6-8; 9-12 & Unit LS2&3)	
mechanism of tasting – detection: taste buds [detect/catch] *molecules/atoms*	4
mechanism of tasting – detection: *each type* of taste bud grabs a *different type* of molecule or: certain atoms/moelcules interact with taste buds differently	2
misconceptions	
taste buds get the sense / feel food	2
different parts of tongue detect different flavors	8

Appendix H. Student Maps

Blair



Casey



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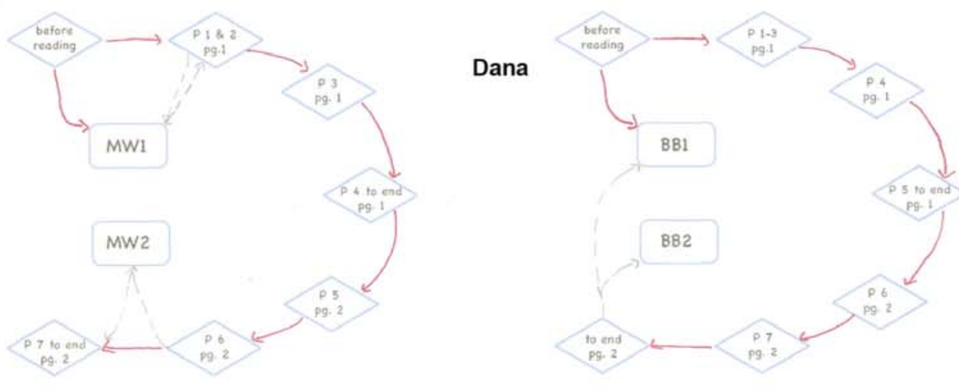
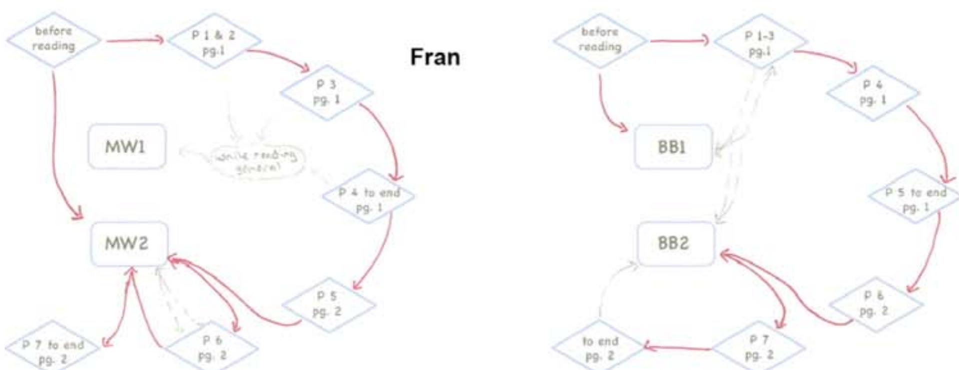


Fran



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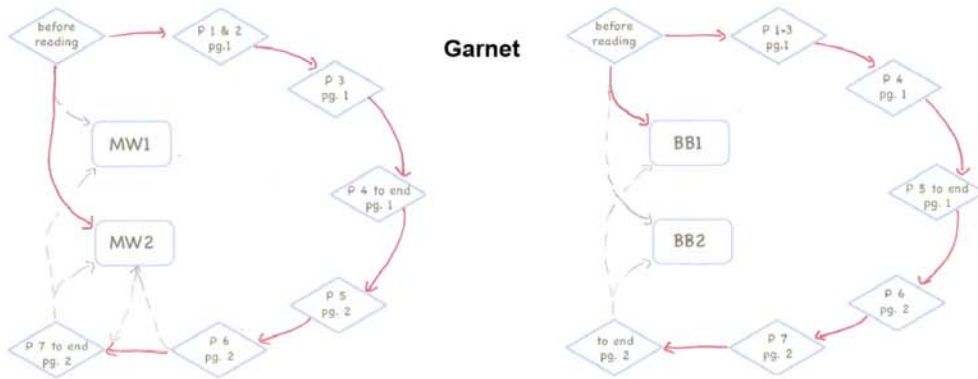

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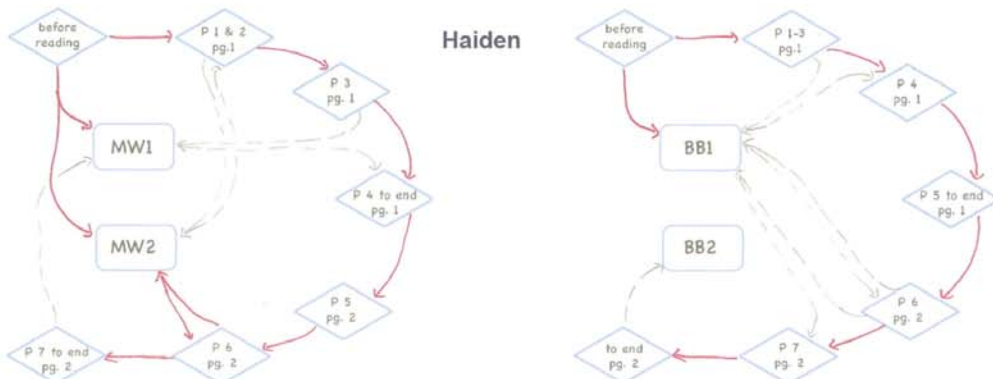
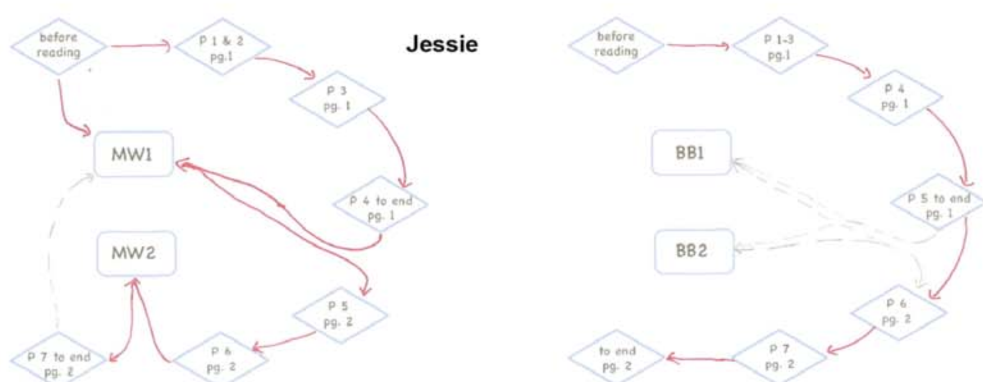
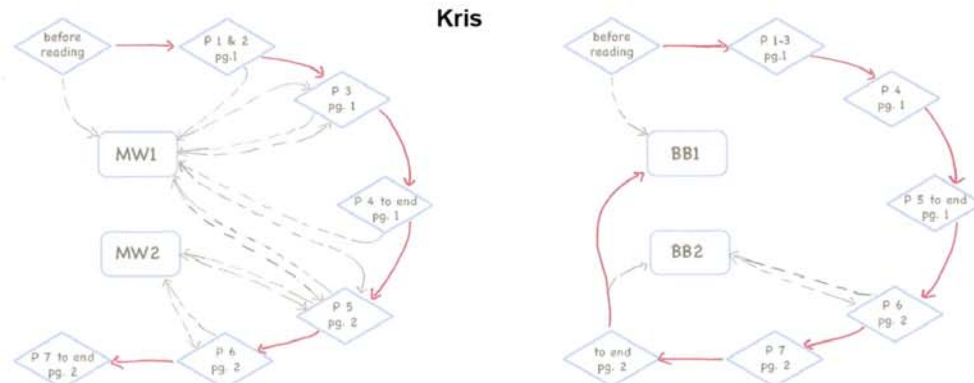
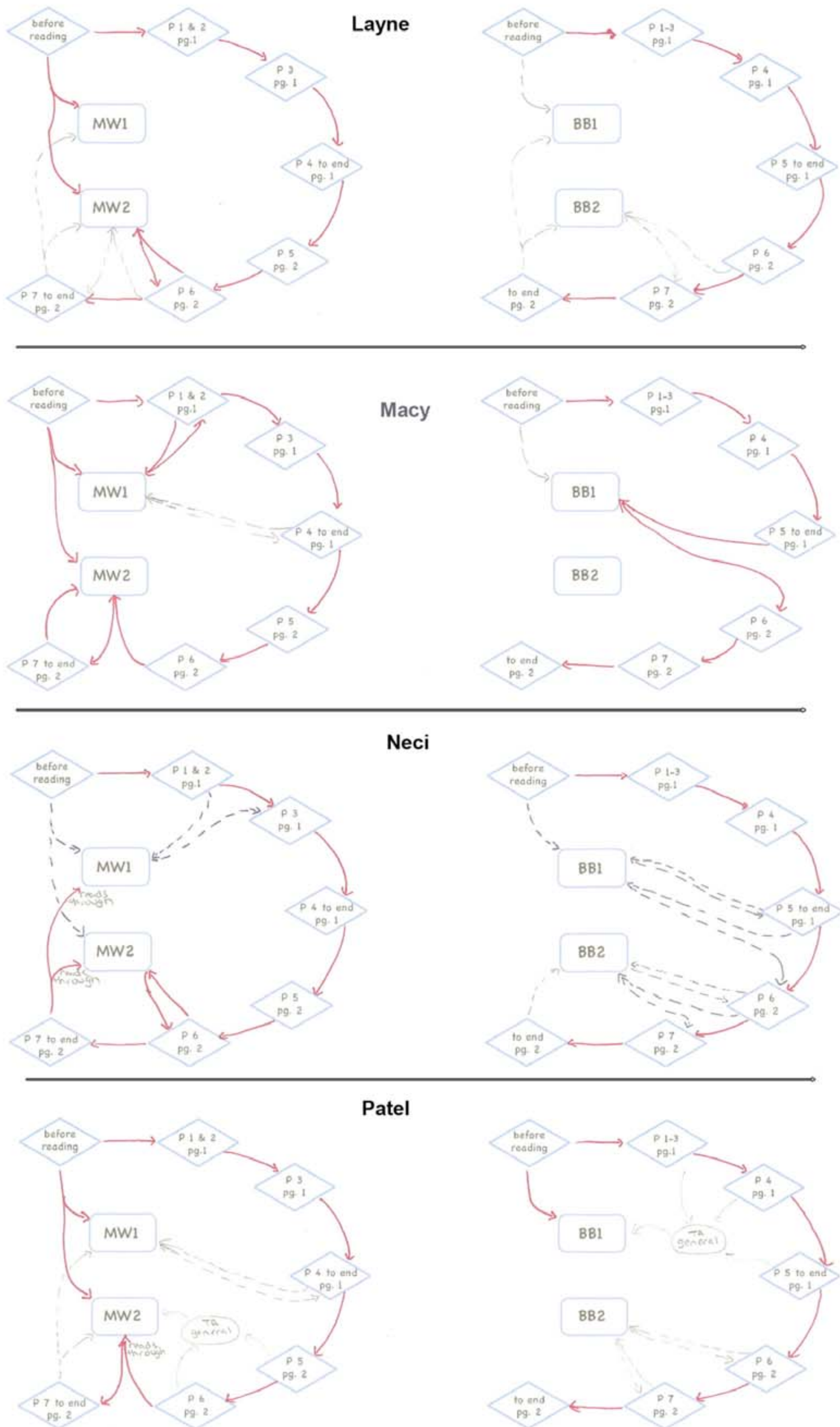


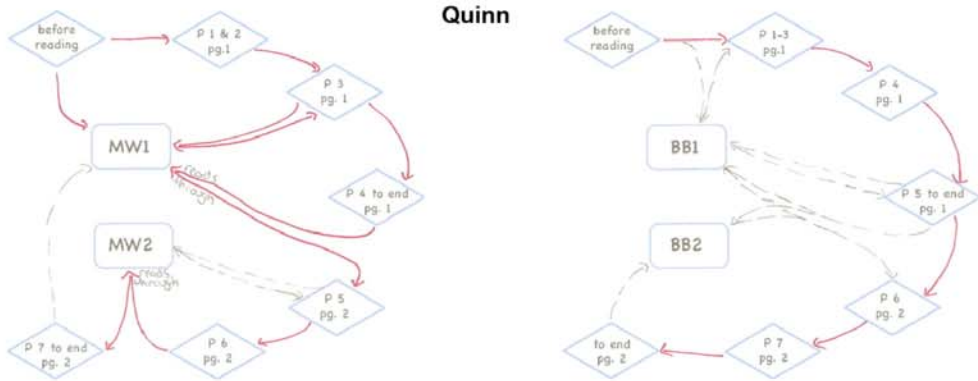
Jessie

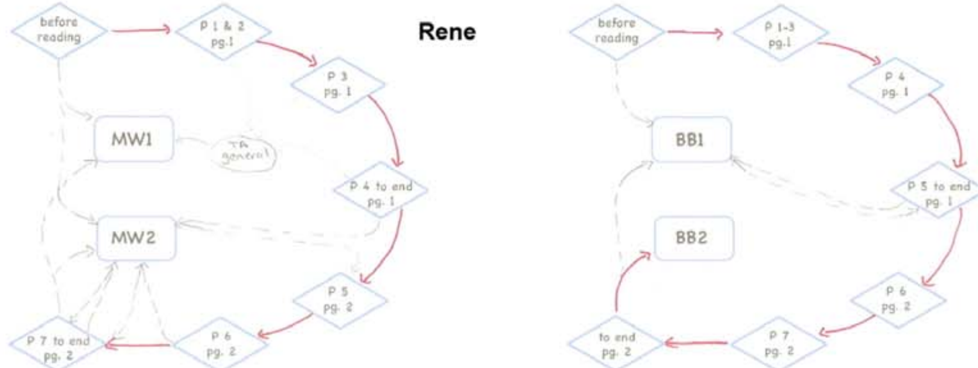


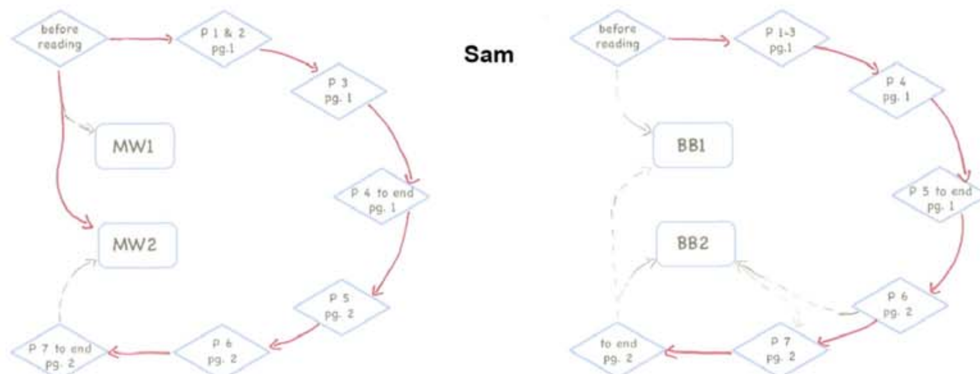
Kris

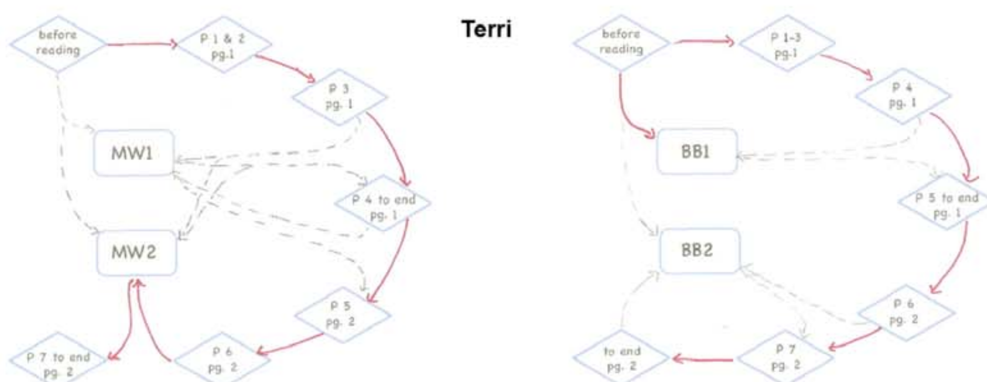



Layne
Macy
Neci
Patel
before reading
P 1 & 2 pg. 1
P 3 pg. 1
P 4 to end pg. 1
P 5 pg. 2
P 6 pg. 2
P 7 to end pg. 2
MW1
MW2
P 1-3 pg. 1
P 4 pg. 1
P 5 to end pg. 1
P 7 pg. 2
to end pg. 2
BB1
BB2
reads through
TA general

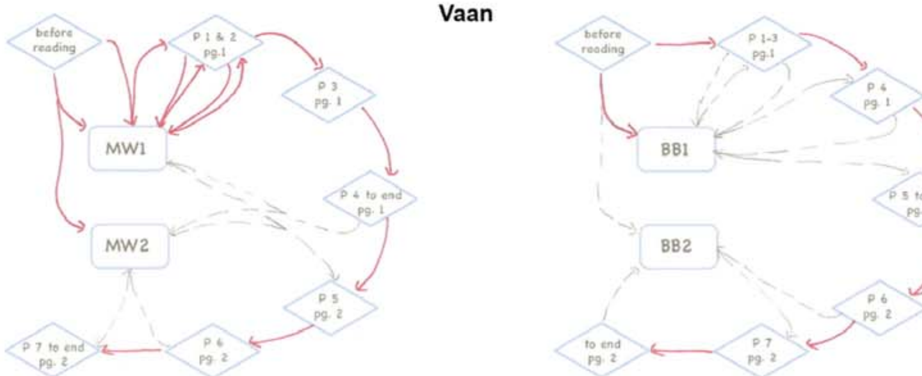

Quinn
before reading
P 1 & 2 pg.1
P 3 pg. 1
MW1
P 4 to end pg. 1
MW2
P 5 pg. 2
P 6 pg. 2
P 7 to end pg. 2
before reading
P 1-3 pg.1
P 4 pg. 1
BB1
P 5 to end pg. 1
BB2
P 6 pg. 2
P 7 pg. 2
to end pg. 2


Rene
before reading
P 1 & 2 pg.1
P 3 pg. 1
MW1
P 4 to end pg. 1
MW2
P 5 pg. 2
P 6 pg. 2
P 7 to end pg. 2
before reading
P 1-3 pg.1
P 4 pg. 1
BB1
P 5 to end pg. 1
BB2
P 6 pg. 2
P 7 pg. 2
to end pg. 2

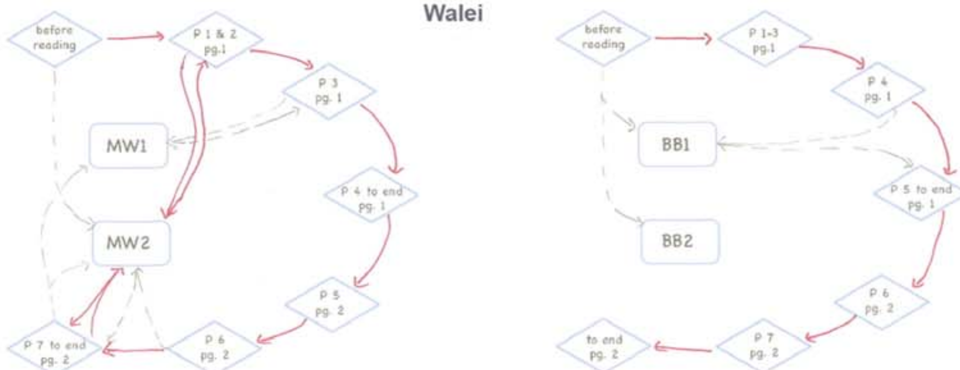

Sam
before reading
P 1 & 2 pg.1
P 3 pg. 1
MW1
P 4 to end pg. 1
MW2
P 5 pg. 2
P 6 pg. 2
P 7 to end pg. 2
before reading
P 1-3 pg.1
P 4 pg. 1
BB1
P 5 to end pg. 1
BB2
P 6 pg. 2
P 7 pg. 2
to end pg. 2


Terri
before reading
P 1 & 2 pg.1
P 3 pg. 1
MW1
P 4 to end pg. 1
MW2
P 5 pg. 2
P 6 pg. 2
P 7 to end pg. 2
before reading
P 1-3 pg.1
P 4 pg. 1
BB1
P 5 to end pg. 1
BB2
P 6 pg. 2
P 7 pg. 2
to end pg. 2

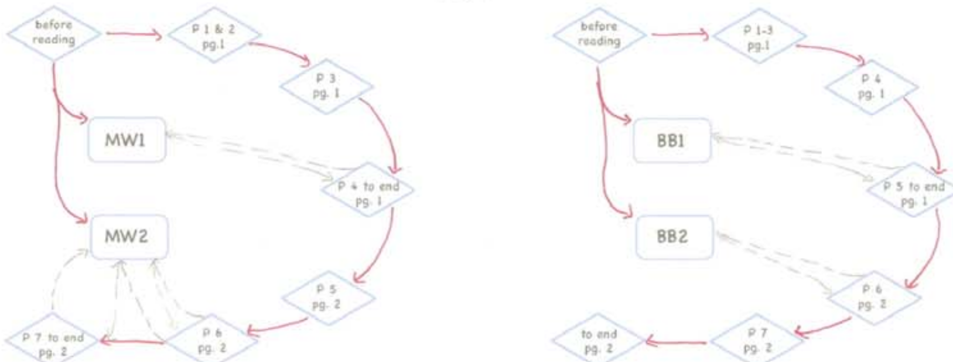
Vaan



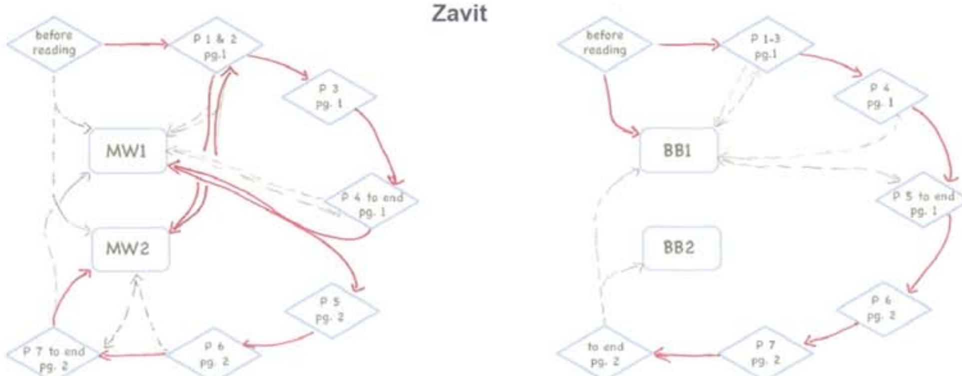
Walei



Xipil



Zavit



APPENDIX I. TWO EXAMPLES OF INCLUDING RECALL IN COMPREHENSION ASSESSMENT

Layne had a low comprehension score for the *Cooking with Ovens* text. However, he recalled a larger percentage of ideas, close to the average percentage of ideas recalled by readers at medial or higher levels for the text. Yet further analysis of the recalled ideas shows that few mapped to the comprehension questions with which he struggled. In Layne's case, the kind of recalled ideas corresponded with his comprehension scores, and supported interpretation of the low scores as struggling with the *Cooking with Ovens* text.

Zavit, on the other hand, is an example of the recalled ideas supporting her comprehension of the text. Zavit scored 50% for the *Bitter Blockers* text. Yet she articulated 44% of the total recalled ideas. Besides retelling more than the average amount of ideas that readers at the medial and higher levels recalled, Zavit also articulated ideas that mapped to comprehension questions with which she struggled. Therefore Zavit's recall supported her comprehension, and I therefore assessed Zavit as comprehending the Bitter Blocker text at the medial level.

REFERENCES

Afflerbach, P., Pearson, P. D., & Paris, S. G. (2008). Clarifying Differences Between Reading Skills and Reading Strategies. *The Reading Teacher, 61*(5), 364-373.

Ainsworth, S. (2008). How Should We Evaluate Multimedia Learning Environments? In J. F. Rouet, R. Lowe & W. Schnotz (Eds.), *Understanding Multimedia Documents* (pp. 249-265). Boston, MA: Springer Science+Business Media.

Alexander, P. A., & Kulikowich, J. M. (1994). A secondary analysis: Learning from physics text. *Journal of Research in Science Teaching, 31*, 895-911.

American Association for the Advancement of Science (AAAS). (1990). *Science for All Americans*. Oxford: Oxford University Press.

American Association for the Advancement of Science (AAAS). (1993). *Benchmarks for science literacy*. New York, NY: Oxford University Press.

American Association for the Advancement of Science (AAAS). (2001). *Atlas of Science Literacy*. Washington, DC: American Association for the Advancement of Science.

Armbruster, B. B., & Anderson, T. H. (1985). Producing "considerate" expository text: Or easy reading is damned hard writing. *Journal of Curriculum Studies, 17*, 247-263.

Barton, M. L., & Jordan, D. L. (2001). *Teaching Reading in Science: A Supplement to "Teaching Reading in the Content Areas Teacher's Manual (2nd Edition)"*. Aurora, CO: McREL (Mid-continent Research for Education and Learning).

Ben-Zvi, R., Eylon, B., & Silberstein, J. (1987). Students' visualization of a chemical reaction. *Education in Chemistry, July*, 117-120.

Berg, C. A., & Phillips, D. G. (1994). An investigation of the relationship between logical thinking structures and the ability to construct and interpret line graphs. *Journal of Research in Science Teaching, 31*(4), 323-344.

Bezemer, J., & Gunther, K. (2009). Visualizing English: a social semiotic history of a school subject. *Visual Communication, 8*(3), 247-262.

Blystone, R. V., & Dettling, B. C. (1990). Visual literacy in science textbooks *What research says to the science teacher - the process of knowing* (Vol. 6, pp. 19-40). Washington, D.C.: NSTA Publications.

Bouillion, L. M., & Gomez, L. M. (2001). Connecting school and community with science learning: Real world problems and school-community partnerships as contextual scaffolds. *Journal of Research in Science Teaching, 38*(8), 878-898.

Bowen, G. M., & Roth, W.-M. (2002). Why students may not learn to interpret scientific inscriptions. *Research in Science Education, 32*, 303-327.

Brophy, J. (1999). Toward a Model of the Value Aspects of Motivation in Education: Developing Appreciation for Particular Learning Domains and Activities. *Educational Psychologist, 34*(2), 75-85.

Brown, A. L. (1985). Teaching students to think as they read: Implications for curriculum reform (Reading Education Report No. 58). Champaign, IL: University of Illinois at Urbana-Champaign, Center for the Study of Reading.

Canham, M., & Hegarty, M. (2010). Effects of knowledge and display design on comprehension of complex graphics. *Learning and Instruction, 20*, 155-166.

Carney, R. N., & Levin, J. R. (2002). Pictorial Illustrations *Still* Improve Students' Learning From Text. *Educational Psychology Review, 14*(1), 5-26.

Carpenter, P. A., & Just, M. A. (1989). The role of working memory in language comprehension. In D. Klahr & K. Kotovsky (Eds.), *Complex information processing: The impact of Herbert A. Simon* (pp. 31-68). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Cognition and Technology Group at Vanderbilt (CTGV). (1992a). Anchored instruction in science and mathematics: Theoretical basis, developmental projects, and initial research findings. In R. A. Duschl & R. Hamilton (Eds.), *April of science, cognitive psychology and educational theory and practice* (pp. 244-273). New York: SUNY Press.

Cognition and Technology Group at Vanderbilt (CTGV). (1992b). The Jasper series as an example of anchored instruction: Theory, program description, and assessment data. *Educational Psychologist, 27*, 291-315.

Cook, L. K., & Mayer, R. E. (1988). Teaching readers about the structure of scientific text. *Journal of Educational Psychology, 80*(4), 448-456.

Cook, M. P. (2006). Visual representations in science education: The influence of prior knowledge and cognitive load theory on instructional design principles. *Science Education, 90*(6), 1073-1091.

Corbin, J., & Strauss, A. (2008). *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory* (3rd ed.). Los Angeles: Sage Publications.

Cordova, D. I., & Lepper, M. R. (1996). Intrinsic Motivation and the Process of Learning: Beneficial Effects of Contextualization, Personalization, and Choice. *Journal of Educational Psychology, 88*(4), 715-730.

Craig, M. T., & Yore, L. D. (1995). Middle school students' metacognitive knowledge about science reading and science text: An interview study. *Reading Psychology, 16*, 169-213.

Craig, M. T., & Yore, L. D. (1996). Middle school students' awareness of strategies for resolving comprehension difficulties in science reading. *Journal of Research and Development in Education, 29*, 226-238.

Cromley, J. G., Snyder-Hogan, L. E., & Luciw-Dubas, U. A. (2010). Cognitive activities in complex science text and diagrams. *Contemporary Educational Psychology, 35*, 59-74.

Davis, E. A., & Krajcik, J. S. (2005). Designing Educative Curriculum Materials to Promote Teacher Learning. *Educational Researcher, 34*, 3-14.

Day, S. (2003, August 26). Tricking the Bitter-Taste Buds: Food Researchers Seek Sweet Disguise, *The New York Times*, p. C8.

DeFrance, N. L. (2008). *Struggling readers learning with graphic-rich digital science text: Effects of a highlight & animate feature and manipulable graphics.* Doctor of Philosophy, The University of Michigan, Ann Arbor, MI.

DeSpezio, M., Linner-Luebe, M., Lisowski, M., Sparks, B., & Skoog, G. (1996). *Science Insights: Exploring Earth and Space*. Menlo Park, CA: Addison-Wesley Publishing Company.
diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and Instruction, 10*(2-3), 105-225.
diSessa, A. A. (2002). Students' Criteria for Representational Adequacy. In K. Gravemeijer, R. Lehrer, B. van Oers & L. Verschaffel (Eds.), *Symbolizing, Modeling and Tool Use in Mathematics Education* (pp. 105-129). Dordrecht, The Netherlands: Kluwer Academic Publishers.
diSessa, A. A. (2004). Metarepresentation: Native Competence and Targets for Instruction. *Cognition and Instruction*, *22*(3), 293-331.
diSessa, A. A., Hammer, D., & Sherin, B. L. (1991). Inventing Graphing: Meta-Representational Expertise in Children. *Journal of Mathematical Behavior, 10*, 117-160.
diSessa, A. A., & Sherin, B. L. (2000). Meta-representation: an introduction. *Journal of Mathematical Behavior, 19*, 385-398.
Donovan, C. A., & Smolkin, L. B. (2002). Considering genre, content, and visual features in the selection of trade books for science instruction. *The Reading Teacher, 55*(6), 502-520.
Eccles, J. S., Wigfield, A., & Schiefele, U. (1998). Motivation to Succeed. In W. Damon & N. Eisenberg (Eds.), *Handbook of child psychology: Social, emotional, and personality development* (5th ed., Vol. 3, pp. 1051-1075). New York, NY: Wiley.
Environmental Waste Association (Producer). (2007). Microwave Information. Retrieved from http://www.ewmc.com/technology/microwave-information.htm
Ericsson, A., & Simon, H. (1984). *Protocol analysis: Verbal reports as data*. Cambridge, MA: MIT Press.
Fielding, L. G., & Pearson, P. D. (1994). Synthesis of Research / Reading Comprehension: What Works. *Educational Leadership, 51*(5), 62-68.
Gabel, D. (1999). Improving Teaching and Learning through Chemistry Education Research: A Look to the Future. *Journal of Chemical Education, 76*(4), 548-554.
Gambrell, L. B., & Jawitz, P. B. (1993). Mental Imagery, Text Illustrations, and Children's Story Comprehension and Recall. *Reading Research Quarterly*, *28*(3), 265-276.
Garner, R. (1987). *Metacognition and reading comprehension*. Norwood, NJ: Ablex.
Garner, R. (1990). When children and adults do not use learning strategies: Toward a theory of Settings. *Review of Educational Research*, *60*(4), 517-529.
Garner, R., Alexander, P. A., Gillingham, M. G., Kulikowich, J. M., & Brown, R. (1991). Interest and Learning from Text. *American Educational Research Journal, 28*(3), 643-659.
Garner, R., Gillingham, M. G., & White, C. S. (1989). Effects of "seductive details" on macroprocessing and microprocessing in adults and children. *Cognition and Instruction*, *6*, 41-57.
Gilbert, J. K. (Ed.). (2005). *Visualization in Science Education* (Vol. 1). Dordrecht, The Netherlands: Springer.

Gilbert, J. K., & Boutler, C. J. (1998). Learning Science Through Models and Modelling. In B. J. Fraser & K. G. Tobin (Eds.), *International Handbook of Science Education*. Great Britain: Kluwer Academic Publishers.

Goldman, S. R., & Bisanz, G. L. (2002). Toward a Functional Analysis of Scientific Genres: Implications for Understanding and Learning Processes In J. Otero, J. A. Leon & A. C. Graesser (Eds.), *The Psychology of Science Text Comprehension* (pp. 19-50). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Goldsmith, E. (1987). The Analysis of Illustration in Theory and Practice. In D. M. Willows & H. A. Houghton (Eds.), *The Psychology of Illustration* (Vol. 2, pp. 53-85). New York, NY: Springer-Verlag.

Graesser, A. C. (2007). An Introduction to Strategic Reading Comprehension. In D. S. McNamara (Ed.), *Reading Comprehension Strategies: Theories, Interventions, and Technologies* (pp. 3-26). New York: Psychology Press.

Grambrell, L. B., & Jawitz, P. B. (1993). Mental Imagery, Text Illustrations, and Children's Story Comprehension and Recall. *Reading Research Quarterly, 28*(3), 265-276.

Guthrie, J. T., & Wigfield, A. (1999). How motivation fits into a science of reading. *Scientific Studies of Reading, 3*(3), 199-205.

Halkia, K., & Mantzouridis, D. (2005). Students' views and attitudes towards the communication code used in press articles about science. *International Journal of Science Education, 27*(12), 1395-1411.

Hand, B. M., Alvermann, D. E., Gee, J., Guzzetti, B. J., Norris, S. P., Phillips, L. M., et al. (2003). Message from the "Island Group": What is Literacy in Science Literacy? *Journal of Research in Science Teaching, 40*(7), 607-615.

Harp, S. F., & Mayer, R. E. (1997). The role of interest in learning from scientific text and illustrations: On the distinction between emotional interest and cognitive interest. *Journal of Educational Psychology, 89*(1), 93-102.

Hegarty, M. (2011). The Cognitive Science of Visual-Spatial Displays: Implications for Design. *Topics in Cognitive Science, 3*(3), 446-474.

Hegarty, M., Carpenter, P. A., & Just, M. A. (1991). Diagrams in the comprehension of scientific texts. In R. Barr, M. L. Kamil & P. B. Mosenthal (Eds.), *Handbook of reading research* (Vol. 2, pp. 641-668). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Hegarty, M., & Just, M. A. (1989). Understanding machines from text and diagrams. In H. Mandl & J. R. Levin (Eds.), *Knowledge acquisition from text and pictures* (pp. 171-194). Amsterdam, The Netherlands: Elsevier.

Heitzman, M. E., Krajcik, J. S., & Davis, E. A. (2004, April 1-3, 2004). *Urban Middle School Students' Use of Various Representations of Chemical Reactions.* Paper presented at the National Association for Research in Science Teaching, Vancouver, British Columbia.

Hidi, S. (2000). An interest researcher's perspective: The effects of extrinsic and intrinsic factors on motivation. In C. Sansone & J. Harackiewicz (Eds.), *Intrinsic and extrinsic motivation: The search for optimal motivation and performance* (pp. 309-339). San Diego, CA: Academic Press.

Hidi, S., & Harackiewicz, J. (2000). Motivating the Academically Unmotivated: A Critical Issue for the 21st Century. *Review of Educational Research, 70*(2), 151-179.

Holliday, W. G. (1976). Teaching verbal chains using flow diagrams and texts. *AV Communication Review, 24*, 63-78.

Holliday, W. G., Yore, L. D., & Alvermann, D. E. (1994). The reading-science learning-writing connection: Breakthroughs, barriers, and promises. *Journal of Research in Science Teaching, 31*, 877-893.

Holmes, B. C. (1987). Children's Inferences with Print and Pictures. *Journal of Educational Psychology, 79*(1), 14-18.

Hubbuch, S. M. (1989). The Trouble with Textbooks. *High School Journal, 72*(4), 203-210.

International Reading Association, & National Council of Teachers of English. (1996). *Standards for the English Language Arts*. Newark, DE: International Reading Assocaition

National Council of Teachers of English.

Johnstone, A. H. (1993). The Development of Chemistry Teaching. *Journal of Chemical Education, 70*(9), 701-705.

Johnstone, A. H. (1997). Chmistry Teaching - Science or Alchemy? 1996 Brasted Lecture. *Journal of Chemical Education, 74*(3), 262-268.

Justi, R., & Gilbert, J. K. (2002). Models and Modelling in Chemical Education. In J. K. Gilbert, O. De Jong, R. Justi, D. F. Treagust & J. H. Van Driel (Eds.), *Chemical Education: Towards Research-based Practice* (Vol. 17, pp. 47-68). Dordrecht: Kluwer Academic Publishers.

Kirby, J. R. (1993). Collaborative and competitive effects of verbal and spatial processes. *Learning and Instruction, 3*, 201-214.

Kletzien, S. B. (1991). Strategy use by good and poor comprehenders reading expository text of different levels. *Reading Research Quarterly, 26*(1), 67-86.

Kolloffel, B. (2012). Exploring the relation between visualizer-verbalizer cognitive styles and performance with visual or verbal learning material. *Computers & Education, 58*(2), 697-706.

Koran, M. L., & Koran, J. J. (1980). Interaction of learner characteristics with pictorial adjuncts in learning from science texts. *Journal of Research in Science Teaching, 17*, 477-483.

Kozma, R. B. (1991). Learning with Media. *Review of Educational Research, 61*(2), 179-211.

Kozma, R. B. (2000). *Representation and Language: The Case for Representational Competence in the Chemistry Curriculum.* Paper presented at the 16th Biennial Conference on Chemical Education, Ann Arbor, MI.

Kozma, R. B. (2003). The material features of multiple representations and their cognitive and social affordances for science understanding. *Learning and Instruction, 13*, 205-226.

Kozma, R. B., & Russell, J. (1997). Multimedia and Understanding: Expert and Novice Responses to Different Representations of Chemical Phenomena. *Journal of Research in Science Teaching, 34*(9), 949-968.

Krajcik, J., & Sutherland, L. M. (2010). Supporting Students in Developing Literacy in Science. *Science, 328*(5977), 456-459.

Krajcik, J. S., Czerniak, C. M., & Berger, C. F. (2003). *Teaching Science in Elementary and Middle School Classrooms: A Project-Based Approach* (2nd ed.). New York, NY: McGraw-Hill.

Krapp, A. (2002). Structural and dynamic aspects of interest development: Theoretical considerations from an ontogenetic perspective. *Learning and Instruction, 12,* 383-409.

Krapp, A., Hidi, S., & Renninger, K. A. (1992). Interest, learning, and development. In K. A. Renninger, S. Hidi & A. Krapp (Eds.), *The role of interest in learning and development*. Hillsdale, NJ: Erlbaum.

Kress, G. R., & Van Leeuwen, T. (2006). *Reading Images: The Grammar of Visual Design* (2nd ed.). London: Routledge.

Latour, B. (1986). *Science in action*. Cambridge, MA: Harvard University Press.

Latour, B. (1990). Drawing things together. In M. Lynch, Steve Woolgar (Ed.), *Representation in Scientific Practice* (pp. 19-68). Cambridge, MA: The MIT Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Lee, H.-S., & Songer, N. B. (2003). Making authentic science accessible to students. *International Journal of Science Education, 25*(8), 923-948.

Lemke, J. L. (1990). *Talking Science: Language, Learning, and Values*. Norwood, NJ: Ablex Publishing.

Lemke, J. L. (1998). Multiplying meaning: Visual and verbal semiotics in scientific text. In J. R. Martin & R. Veel (Eds.), *Reading Science* (pp. 87-113). London: Routledge.

Lepper, M. R., & Hodell, M. (1989). Intrinsic motivation in the classroom. In C. Ames & R. Ames (Eds.), *Research on motivation in education* (Vol. 3, pp. 73-105). San Diego, CA: Academic Press.

Leslie, L., & Caldwell, J. (2000). *Qualitative Reading Inventory III*. New York, NY: Longman.

Lowe, R. K. (2000). Visual Literacy and Learning in Science. ERIC Digest. (pp. 00-02). Columbus, OH: ERIC Clearinghouse for Science, Mathematics, and Environmental Education.

Lynch, M., & Woolgar, S. (1990). *Representation in Scientific Practice*. Cambridge, MA: MIT Press.

Martins, I. (2002). Visual Imagery in School Science Texts. In J. Otero, J. A. Leon & A. C. Graesser (Eds.), *The Psychology of Science Text Comprehension* (pp. 73-90). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Mayer, R. E. (1993). Commentary: Comprehension of graphics in texts: An overview. *Learning and Instruction, 3*, 239-245.

Mayer, R. E. (1994). Visual aids to knowledge construction: Building mental representations from pictures and words. In W. Schnotz & R. W. Kulhavy (Eds.), *Comprehension and Graphics* (pp. 125-138). Amsterdam, Netherlands: Elsevier Science Publishers.

Mayer, R. E. (1997). Multimedia Learning: Are we asking the right questions? *Educational Psychologist, 32*(1), 1-19.
Mayer, R. E. (2001). *Multimedia Learning*. Cambridge, UK: Cambridge University Press.
Mayer, R. E., & Gallini, J. K. (1990). When is an illustration worth ten thousand words? *Journal of Educational Psychology, 82*(4), 715-726.
Mayer, R. E., & Sims, V. K. (1994). For whom is a picture worth a thousand words? Extensions of dual-coding theory of multimedia learning. *Journal of Educational Psychology, 86*(3), 389-401.
McDiarmid, Ball, D. L., & Anderson, C. W. (1989). Why Staying One Chapter Ahead Doesn't Really Work: Subject-Specific Pedagogy. In McReynolds (Ed.), *Knowledge Base for the Beginning Teacher* (pp. 103-205). New York: Pergamon.
McGinn, M. K., & Roth, W. M. (1999). Preparing Students for Competent Scientific Practice: Implications of recent research in science and technology studies. *Educational Researcher, 28*(3), 14-24.
McNamara, D. S. (2007). Preface. In D. S. McNamara (Ed.), *Reading Comprehension Strategies: Theories, Interventions, and Technologies* (pp. xi-xv). New York: Psychology Press.
McNeill, K. L., & Krajcik, J. S. (2008). Scientific Explanations: Characterizing and Evaluating the Effects of Teachers' Instructional Practices on Student Learning. *Journal of Research in Science Teaching, 45*(1), 53-78.
McNeill, K. L., Lizotte, D. J., Harris, C. J., Scott, L. A., Krajcik, J. S., & Marx, R. W. (2003, March, 2003). *Using Backward Design to Create Standards Based Middle School Inquiry-Oriented Chemistry Curriculum and Assessment Materials.* Paper presented at the National Association for Research in Science Teaching, Philadelphia, PA.
McTigue, E. M. (2009). Does multimedia learning theory extend to middle-school students? *Contemporary Educational Psychology, 34*(2), 143-153.
McTigue, E. M., & Croix, A. (2010). Visual Literacy in Science. *Science Scope, 33,* 17-22.
McTigue, E. M., & Flowers, A. C. (2011). Science Visual Literacy: Learners' Perceptions and Knowledge of Diagrams. *The Reading Teacher, 64*(8), 578-589.
Merritt, J. D., Dalpe, S. D., Heitzman, M. E., Shwartz, Y., Sutherland, L. M., & Krajcik, J. S. (2006). How can I smell things from a distance? In J. Krajcik & B. J. Reiser (Eds.), *IQWST: Investigating and Questioning our World through Science and Technology*. Ann Arbor, MI: University of Michigan.
Meyer, B. J. F., & Freedle, R. O. (1984). Effects of Discourse Type on Recall. *American Educational Research Journal, 21*(1), 121-143.
Moje, E. B. (2005). [Discussion of ways students comprehend text].
Moje, E. B., Dillon, D. R., & O'Brien, D. G. (2000). Re-examining the roles of the learner, the text, and the context in secondary literacy. *Journal of Educational Research, 93*(165-180).
Moje, E. B., Peek-Brown, D., Sutherland, L. M., Marx, R. W., Blumenfeld, P. C., & Krajcik, J. S. (2004). Explaining explanations: Developing scientific literacy in middle-school project-based science reforms. In D. Strickland & D. E. Alvermann (Eds.), *Bridging the Gap: Improving Literacy Learning for Preadolescent and*

Adolescent Learners in Grades 4-12 (pp. 227-251). New York: Teachers College Press.
Moje, E. B., Sutherland, L. M., Cleveland, T. E., & Heitzman, M. E. (2005, November). *Reading and writing in science: Multiple text types in scientific literacy learning.* Paper presented at the Annual Meeting of the National Reading Conference, Miami, FL.
Mokhtari, K., & Reichard, C. A. (2002). Assessing Students' Metacognitive Awareness of Reading Strategies. *Journal of Educational Psychology, 94*(2), 249-259.
Moore, P. J., Chan, L. K. S., & Au, W. K. (1993). High school students' use of diagrams during reading. *Journal of Research in Reading, 16*(1), 57-71.
Moore, P. J., & Scevak, J. J. (1997). Learning from texts and visual aids: a developmental perspective. *Journal of Research in Reading, 20*(3), 205-223.
Moses, R. P. (2001). *Radical Equations: Civil Rights from Mississippi to the Algebra Project*. Boston, Massachusetts: Beacon Press.
National Governors Association Center for Best Practices (NGA Center), & Council of Chief State School Officers (CCSSO). (2010). Common Core State Standards for English Language Arts & Literacy in History/Social Studies, Science and Technical Subjects. Washington, D.C.: National Governors Association Center for Best Practices, Council of Chief State School Officers.
National Research Council (NRC). (1996). *National Science Education Standards.* Washington, DC: National Academy Press.
National Research Council (NRC). (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, D.C.: National Academies Press.
New York Times News Service. (1985, November 24). Microwaving Saves Vitamins, *Chicago Tribune,* p. 20.
Ochs, E., Gonzales, P., & Jacoby, S. (1996). When I come down I'm in the domain state... In E. Ochs, E. Schegloff & T. S. (Eds.), *Interaction and Grammar*. Cambridge: Cambridge University Press.
Paivio, A. (1986). *Mental representations: A dual coding approach*. New York: Oxford University Press.
Palincsar, A. S. (2001). The Interplay of First-Hand and Second-Hand Investigations to Model and Support the Development of Scientific Knowledge and Reasoning. In S. Carver & D. Klahr (Eds.), *Cognition and Instruction: Twenty-five Years of Progress* (pp. 151-194). Mahwah, NJ: Lawrence Erlbaum Associates.
Palincsar, A. S., Dalton, B., & Magnusson, S. J. (2005, May). *Reading to Learn: A tool for supporting struggling (and all) readers to make sense of science text.* Paper presented at the International Reading Association Annual Convention Pre-Conference Institute, San Antonio, TX.
Palincsar, A. S., & Magnusson, S. J. (1997a). *The interaction of first and second hand investigations in guided inquiry science teaching*.
Palincsar, A. S., & Magnusson, S. J. (1997b). *The role of text in supporting and extending first-hand investigations in guided inquiry science instruction.* Paper presented at the National Reading Conference, Scottsdale, AZ.
Palincsar, A. S., & Schutz, K. M. (2011). Reconnecting Strategy Instruction With Its Theoretical Roots. *Theory Into Practice, 50*, 85-92.

Paris, S. G., & Winograd, P. N. (1990). How metacognition can promote academic learning and instruction. In B. F. Jones & L. Idol (Eds.), *Dimensions of thinking and cognitive instruction*. Hillsdale, NJ: Erlbaum.

Parr, C. S., Jones, T., & Songer, N. B. (2004). Evaluation of a Handheld Data Collection Interface for Science Learning. *Journal of Science Education and Technology, 13*(2), 233-242.

Pearson, P. D., Moje, E. B., & Greanleaf, C. (2010). Literacy and Science: Each in the Service of the Other. *Science*, *328*, 459-463.

Peeck, J. (1993). Increasing Picture Effects in Learning from Illustrated Text. *Learning and Instruction*, *3*, 227-238.

Pelligrino, J. W., Chudowsky, N., & Glaser, R. (2001). *Knowing What Students Know: The Science and Design of Educational Assessment*. Washington, D.C.: National Academy Press.

Piaget, J. (1969). *The Psychology of the Child*. New York, NY: Basic Books, Inc.

Pintrich, P. R., & Schunk, D. (2002). *Motivation in Education: Theory, Research and Applications* (2nd ed.). Upper Saddle River, NJ: Merrill Prentice Hall.

RAND, R. S. G. (2002). *Reading for Understanding: Toward an R&D Program in Reading Comprehension*. Santa Monica, CA: RAND Corporation.

Reiser, B. J., Krajcik, J. S., Moje, E. B., & Marx, R. W. (2003). *Design strategies for developing science instructional materials.* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Philadelphia, PA.

Richgels, D. J., McGee, L. M., Lomax, R. G., & Sheard, C. (1987). Awareness of Four Text Structures: Effects on Recall of Expository Text. *Reading Research Quarterly, 22*(2), 177-196.

Rivet, A. E., & Krajcik, J. S. (2008). Contextualizing Instruction: Leveraging Students' Prior Knowledge and Experiences to Foster Understanding of Middle School Science. *Journal of Research in Science Teaching, 45*(1), 79-100.

Robinson, D. H. (2002). Spatial Text Adjuncts and Learning: An Introduction to the Special Issue. *Educational Psychology Review, 14*(1), 1-3.

Roseman, J. E., Kesidou, S., Stern, L., & Caldwell, A. (1999). Heavy Books Light on Learning: AAAS project 2061Evaluates Middle Grades Science Textbooks. *Science Books & Films, 35*(6).

Roth, W.-M., Bowen, G. M., & McGinn, M. K. (1999). Differences in graph-related practices between high school biology textbooks and scientific ecology journals. *Journal of Research in Science Teaching, 36*, 977-1019.

Roth, W.-M., & Lee, S. (2004). Science Education as/for Participation in the Community. 263-291.

Roth, W.-M., & McGinn, M. K. (1998). Inscriptions: Toward a Theory of Representing as Social Practice. *Review of Educational Research, 68*(1), 35-59.

Rouet, J.-F., Lowe, R., & Schnotz, W. (2008). Understanding Multimedia Documents: An introduction. In J.-F. Rouet, R. Lowe & W. Schnotz (Eds.), *Understanding Multimedia Documents* (pp. 1-14). New York: Springer.

Rusted, R., & Coltheart, V. (1979). The effect of pictures on the retention of novel words and prose passages. *Journal of Experimental Child Psychology, 28*, 516-524.

Sadoski, M., & Paivio, A. (2001). *Imagery and Text: A dual coding theory of reading and writing*. Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

Sanchez, C. A., & Wiley, J. (2006). An examination of the seductive details in terms of working memory capacity. *Memory and Cognition, 34*(2), 344-355.

Schellings, G. L. M., & Van Hout-Wolters, B. H. A. M. (1995). Main Points in an Instructional Text, as Identified by Students and by Their Teachers. *Reading Research Quarterly, 30*(4), 742-756.

Schiefele, U. (1999). Interest and learning from text. *Scientific Studies of Reading, 3*(3), 257-279.

Schlag, S., & Ploetzner, R. (2011). Supporting learning from illustrated texts: Conceptualizing and evaluating a learning strategy. *Instructional Science, 39*(6), 921-937.

Schnotz, W. (1993). Introduction. *Learning and Instruction, 3*(3), 151-155.

Schnotz, W. (2002). Commentary: Towards an Integrated View of Learning From Text and Visual Displays. *Educational Psychology Review, 12*(1), 101-120.

Schnotz, W. (2008). Why multimedia learning is not always helpful. In J. F. Rouet, R. Lowe & W. Schnotz (Eds.), *Understanding Multimedia Documents* (pp. 17-41). New York: Springer.

Schnotz, W., & Bannert, M. (2003). Construction and interference in learning from multiple representations. *Learning and Instruction, 13*(2), 141-156.

Schnotz, W., Bannert, M., & Seufert, T. (2002). Toward an Integrative View of Text and Picture Comprehension: Visualization Effects on the Construction of Mental Models. In J. Otero, J. A. Leon & A. C. Graesser (Eds.), *The Psychology of Science Text Comprehension*. Mahwah, New Jersey: Lawrence Erlbaum Associates, Publishers.

Schnotz, W., & Kurschner, C. (2007). A reconsideration of cogntive load theory. *Educational Psychology Review, 19*(4), 469-508.

Schnotz, W., & Lowe, R. (2008). A Unified View of Learning from Animated and Static Graphics. In R. Lowe & W. Schnotz (Eds.), *Learning with Animation: Research Implications for Design* (pp. 304-356). Cambridge: Cambridge University Press.

Schnotz, W., Picard, E., & Hron, A. (1993). How do successful and unsucessful learners use texts and graphics? *Learning and Instruction, 3*, 181-199.

Schnotz, W., Ullrich, M., Hochpochler, U., Horz, H., McElvany, N., Schroeder, S., et al. (2011). What makes text-picture-integration difficult? A structural and procedural analysis of textbook requirements. *Ricerche di Psicologia, 1*, 103-135.

Schroeder, S., Richter, T., McElvany, N., Hachfeld, A., Baumert, J., Schnotz, W., et al. (2011). Teachers' beliefs, instructional behaviors, and students' engagement in learning from texts with instructional pictures. *Learning and Instruction, 21*, 403-415.

Snow, C. E. (2010). Academic Language and the Challenge of Reading for Learning about Science. *Science, 328*(5977), 450-452.

Solomon, T. C., Van de Kerkhof, M. H., & Moje, E. B. (2010). When is a detail seductive? On the challenges of constructing and teaching from engaging science texts. In A. J. Rodriguez (Ed.), *Science Education as a Pathway to Teaching Language Literacy*. Rotterdam, The Netherlands: Sense Publishers.

Stieff, M., Hegarty, M., & Deslongchamps, G. (2011). Identifying representational competence with multi-representational displays. *Cognition and Instruction, 29*(1), 123-145.
Stieff, M., & McCombs, M. (2006). *Increasing representational fluency with visualization tools.* Paper presented at the Proceedings fo the Seventh Annual International Conference of the Learning Sciences (ICLS).
Stieff, M., Stillings, N., Arasasingham, R., Taagepera, M., & Wamser, C. (2004, April 1-3, 2004). *Characterizing chemistry problem solving with convergent approaches form chemistry, education, and psychology.* Paper presented at the National Association for Research in Science Teaching, Vancouver, British Columbia.
Strauss, A., & Corbin, J. (1990). *Basics of Qualitative Research: Grounded Theory Procedures and Techniques*. Newbury Park, CA: Sage Publications.
Sutherland, L. M., Hug, B., Moje, E. B., & Krajcik, J. S. (2005). *Curriculum Reaer Design Principles*. IQWST Kickoff Meeting. University of Michigan. Ann Arbor.
The New London Group. (1996). A Pedagogy of Multiliteracies: Designing Social Futures. *Harvard Educational Review, 66*(1), 60-92.
Tierney, R. J., & Pearson, P. D. (1992). Learning to learn from text: A framework for improving classroom practice. In (Eds.), Reading in the content areas: Improving classroom instruction. (pp. 82-86). Dubuque, IA: Kendall/Hunt. In E. K. Dishner, T. W. Bean, J. E. Readence & D. W. Moore (Eds.), *Reading in the content areas: Improving classroom instruction* (3rd ed., pp. 82-86). Dubuque, IA: Kentall/Hunt.
Treagust, D. F., & Chitleborough, G. (2001). Chemistry: A matter of understanding representations *Subject-Specific Instructional Methods and Activities* (Vol. 8, pp. 239-267): Elsevier Science Ltd.
Vacca, R. T., & Vacca, J. L. (1993). *Content Area Reading* (4th ed.). New York, NY: HarperCollins Publishers.
van den Broek, P. (2010). Using Texts in Science Education: Cognitive Processes and Knowledge Representation. *Science, 328*(23), 453-456.
Van Dijk, T. A., & Kintsch, W. (1983). *Strategies of Discourse Comprehension*. New York: Academic Press.
Vygotsky, L. S. (1978). *Mind in Society*. Cambridge, MA: Harvard University Press.
Wandersee, J. H. (1988). Ways students read texts. *Journal of Research in Science Teaching, 25*(1), 69-84.
Wheeler-Toppen, J. (2010). *Once Upon a Life Science Book: 12 Interdisciplinary Activities to Create Confident Readers*. Arlington, VA: National Science Teachers Association (NSTApress).
Winn, W. (1987). Charts, Graphs, and Diagrams in Educational Materials. In D. M. Willows & H. A. Houghton (Eds.), *The Psychology of Illustration* (Vol. 1, pp. 152-198). New York, NY: Springer-Verlag.
Winn, W. (1991). Learning from maps and diagrams. *Educational Psychology Review, 3,* 211-247.
Winograd, P. N. (1984). Strategic Difficulties in Summarizing Texts. *Reading Research Quarterly, 19*(4), 404-425.
Wood, J. M. (2007). Understanding and Computing Cohen's Kappa: A Tutorial. *WebPsychEmpiricist*, 1-18. Retrieved from http://wpe.info/papers_table.html

Wu, H.-K. (2002). *Middle School Students' Development of Inscriptional Practices in Inquiry-Based Science Classrooms.* Dissertation, University of Michigan, Ann Arbor, MI.

Wu, H.-K. (2003). Linking the Microscopic View of Chemistry to Real-Life Experiences: Intertextuality in a High-School Science Classroom. *Science Education*, *87*, 868-891.

Wu, H.-K., Krajcik, J. S., & Soloway, E. (2001). Promoting Understanding of Chemical Representations: Students' Use of a Visualization Tool in the Classroom. *Journal of Research in Science Teaching, 38*(7), 821-842.

Yore, L. D., Craig, M. T., & Maguire, T. O. (1998). Index of Science Reading Awareness: An Interactive-Constructive Model, Test Verification, and Grades 4-8 Results. *Journal of Research in Science Teaching, 35*(1), 27-51.

Yore, L. D., & Shymansky, J. A. (1991). Reading in science: Developing an operational conception to guide instruction. *Journal of Science Teacher Education, 2*(2), 29-36.