Exploring Middle School Students' Representational Competence in Science: Development and Verification of a Framework for Learning with Visual Representations

by

Christine Diane Tippett

B.A.Sc., University of British Columbia, 1987
B.Ed., University of Victoria, 1993
M.A., University of Victoria, 2004

A Dissertation Submitted in Partial Fulfillment of the
Requirements for the Degree of

DOCTOR OF PHILOSOPHY

in the Department of Curriculum and Instruction

Supervisory Committee

Exploring Middle School Students' Representational Competence in Science:

Development and Verification of a Framework for Learning

with Visual Representations

by

Christine Diane Tippett

B.A.Sc., University of British Columbia, 1987
B.Ed., University of Victoria, 1993
M.A., University of Victoria, 2004

Supervisory Committee

Dr. Larry D. Yore, Department of Curriculum and Instruction
Supervisor

Dr. Robert J. Anthony, Department of Curriculum and Instruction
Departmental Member

Dr. Deborah Begoray, Department of Curriculum and Instruction
Departmental Member

Dr. Sylvia Pantaleo, Department of Curriculum and Instruction
Departmental Member

Dr. John O. Anderson, Department of Educational Psychology and Leadership Studies
Outside Member

Abstract

Supervisory Committee
Dr. Larry D. Yore, Department of Curriculum and Instruction
Supervisor
Dr. Robert J. Anthony, Department of Curriculum and Instruction
Departmental Member
Dr. Deborah Begoray, Department of Curriculum and Instruction
Departmental Member
Dr. Sylvia Pantaleo, Department of Curriculum and Instruction
Departmental Member
Dr. John O. Anderson, Department of Educational Psychology and Leadership Studies
Outside Member

Scientific knowledge is constructed and communicated through a range of forms in addition to verbal language. Maps, graphs, charts, diagrams, formulae, models, and drawings are just some of the ways in which science concepts can be represented. Representational competence—an aspect of visual literacy that focuses on the ability to interpret, transform, and produce visual representations—is a key component of science literacy and an essential part of science reading and writing. To date, however, most research has examined learning *from* representations rather than learning *with* representations. This dissertation consisted of three distinct projects that were related by a common focus on learning from visual representations as an important aspect of scientific literacy. The first project was the development of an exploratory framework that is proposed for use in investigations of students constructing and interpreting multimedia texts. The exploratory framework, which integrates cognition, metacognition, semiotics, and systemic functional linguistics, could eventually result in a model that might be used to guide classroom practice, leading to improved visual literacy, better comprehension of science concepts, and enhanced science literacy because it emphasizes distinct aspects of learning with representations that can be addressed though explicit instruction. The second project was a metasynthesis of the research that was previously conducted as part of the *Explicit Literacy Instruction Embedded in Middle School Science* project (Pacific CRYSTAL, http://www.educ.uvic.ca/pacificcrystal). Five overarching themes emerged from this case-to-case synthesis: the engaging and effective nature of multimedia genres, opportunities for differentiated instruction using multimodal strategies, opportunities for assessment, an emphasis on visual representations, and the robustness of some multimodal literacy strategies across content areas. The third project was a mixed-methods verification study that was conducted to refine and validate the theoretical framework. This study examined middle school students' representational competence and focused on students' creation of visual representations such as labelled diagrams, a form of representation commonly found in science information texts and textbooks. An analysis of the 31 Grade 6 participants' representations and semistructured interviews revealed five themes, each of which supports one or more dimensions of the exploratory framework: participants' use of color, participants' choice of representation (form and function), participants' method of planning for representing, participants' knowledge of conventions, and participants' selection of information to represent. Together, the results of these three projects highlight the need for further research on learning *with* rather than learning *from* representations.

Table of Contents

List of Tables

List of Figures

Acknowledgements

A heartfelt thank you goes to Dr. Larry D. Yore for his unending support throughout my time in the doctoral program. His influence upon my academic career began many years ago when he was the instructor for my science methods course and continued when he was a committee member during my Master's program. Dr. Yore's understanding during personally challenging times meant a great deal to me and allowed me to obtain my PhD in a timely manner. His mentorship has played a significant role in shaping my research and publication accomplishments.

Thanks also go to Dr. Todd Milford for his help with the statistical aspects of the dissertation. Our periodic discussions about academic issues have also played an important part in my professional growth. Here's to continued research collaboration, regardless of our ultimate institutional destinations.

In addition, I want to acknowledge Shari Yore for her careful editing of this dissertation. The final copy adheres to 6th edition APA format, with all its quirks!

Finally, thanks to my friends and family for their encouragement as I embarked once again on an academic adventure.

Chapter 1
Overview

Scientific knowledge is constructed and communicated through a range of texts and forms in addition to verbal language. Maps, graphs, charts, diagrams, formulae, models, and drawings are just some of the ways in which science concepts can be represented (Lynch, 2001). Representational competence—an aspect of visual literacy that focuses on the ability to interpret, transform, and produce visual representations—is therefore a key component of science literacy and an essential part of science reading and writing.

This dissertation consists of three distinct yet related projects in addition to a literature review. The first project was the development of an exploratory framework that I propose for use in investigations of students constructing and interpreting multimedia texts containing both verbal and visual elements, which may be static or dynamic in nature. The second project was a metasynthesis of the research that I conducted as part of the *Explicit Literacy Instruction Embedded in Middle School Science* project, one of several projects overseen by the Pacific Centre for Research in Youth, Science Teaching, and Learning (Pacific CRYSTAL), which is located at the University of Victoria (http://www.educ.uvic.ca/pacificcrystal). The third project was the verification study, the empirical research that I conducted in the process of refining and validating the theoretical framework. The verification study examined middle school students' representational competence and focused on students' creation of visual representations such as labelled diagrams, a form of representation commonly found in science information texts and textbooks. These three projects are connected by a common focus on the use of visual representations in science.

Rationale for the Project

The important role of visual representations in science has recently become an international research focus as evidenced by special issues of the *International Journal of Science Education* (Visual and Spatial Modes in Science Learning, February 2009) and *Research in Science Education* (Representing Science Literacies, January 2010). Science education researchers have explored the use of visual representations by examining multiple representations (e.g., Eilam & Poyas, 2008; Kozma, 2003), multimedia representations (e.g., Mayer, 2001), and multimodal representations (e.g., Márquez, Izquierdo, & Espinet, 2006).

However, much of the research on representational competence in science has focused on the interpretation and comprehension of visual representations, rather than examining students' creation of those representations. In addition, there have been few studies conducted in the science classroom and even fewer studies in which students younger than university or high school have participated. The dissertation program of research was intended to more fully describe four areas that are currently insufficiently addressed in the visual literacy and representational competence literature:

- Developing a coherent framework that is appropriate for use with future classroom-based research addresses the current lack of such a theoretical foundation.
- Implementing a classroom-based program of research addresses the need for investigations in authentic contexts.
- Focusing on middle school students addresses the lack of research examining the representational competence of students younger than high school age.
- Exploring students' construction of representations complements research that has examined comprehension rather than creation.

The problem space central to this program of investigation is learning *with* multimedia science texts that contain both print and visual information. Learning *from* multimedia texts has been an area of interest for science education researchers for decades, which has resulted in a well-developed problem space and provided insights for reading and making sense of prepared texts. However, it is only recently that the focus has shifted to learning *with* multimedia text, which occurs when students generate their own multimedia representations of science concepts. The unique nature of the language of science is central to this enlarged and less well-defined problem space.

The Importance of Representational Competence in Science

Scientific reading and writing typically includes not only print but also nonverbal components, such as labelled photographs, tables, equations, animations, graphs, and diagrams. These highly specialized representations are essential tools for conceptualizing scientific ideas (Lemke, 1998; Martins, 2002). Full comprehension of informational text replete with nonverbal components requires visual literacy—more specifically representational competence—because readers and writers must understand the range of forms that such representations can take and the conventions of each form (Lowe, 2000). The process of creating visual representations can lead to deeper understanding of the scientific concepts being portrayed as knowledge is transformed from one mode to another (Pérez Echeverria, Postigo, & Pecharroman, 2010). Siegel (1995) referred to the translation of meanings between sign systems as the process of transmediation and noted that transmediation facilitated connections and meaning making.

Aspects of representational competence include selecting the most appropriate forms for communicating particular information or for constructing knowledge (Ainsworth, 2008; Moline, 1995). For example, would a diagram or a graph be the most efficient and accurate way to display certain information? If a graph would be the most efficient, what type of graph is most appropriate: line, bar, or pie chart? What does a bar graph reveal about the phenomenon under investigation? Students (and scientists) who possess representational competence are able to make such decisions based on an understanding of the conventions of the forms of representations. In the past, verbal modes (print or auditory) carried the main message of a text while visual modes (static or dynamic representations) played supporting roles as aids to visualization or as elements intended to interest or engage the reader (Martins, 2002). Modern science texts tend to be more complex, with representations that can contain as much information as (and sometimes more than) the verbal components. Figure 1 provides an example of verbal and visual science information displayed in a complementary relationship; each mode contains details that are essential for full understanding of the concept of transparency.

Situating Visual Literacy in the Context of Science Literacy

Representational competence is an aspect of visual literacy—one of the features of science literacy—which is the goal of science education internationally as well as a focus in recent science education research literature (e.g., Millar, 2006; Yore & Hand, 2010; Yore & Treagust, 2006). People who are scientifically literate have the understanding and abilities needed for full and informed participation in public debates about science, technology, society, and the environment (STSE) issues (Council of Ministers of Education, Canada [CMEC], 1997; United States National Research Council [USNRC], 1996). However, there is a lack of consensus regarding a more precise definition of scientific literacy—including the role played by visual literacy—even though the term has been in use since Hurd's (1958) article in *Educational Leadership* (Hurley, 1998).

10.3 Getting in Light's Way

Imagine a world without glass. Your school would be very different—and very dark. When choosing materials, designers and engineers need to consider which materials block light and which materials, such as glass, let light pass through. **Transparency** is a measure of how much light can pass through a material. Materials are classified as transparent, translucent, or opaque.

Plastic wrap is transparent (**Figure 1**). Particles in a **transparent** material let light pass through easily. A clear image can be seen through the material. Plate glass, air, and shallow, clear water are examples of transparent materials.

LEARNING TIP

Check your understanding of transparent, translucent, and opaque materials by explaining **Figures 1** to **3** to a partner.

Skin is a translucent material (**Figure 2**). Particles in a **translucent** material transmit light, but also reflect some, so a clear image cannot be seen through the material. Frosted glass, clouds, and your fingernails are translucent materials.

A glass of milk is opaque (**Figure 3**). Particles in an **opaque** material do not allow any light to pass through. All the light energy is either absorbed or reflected. Most materials are opaque. For example, building materials, such as wood, stone, and brick, are opaque.

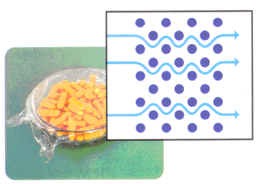


Figure 1
Transparent materials allow all light to pass through.

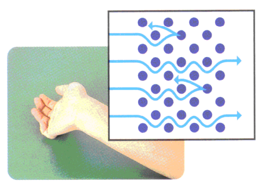


Figure 2
Translucent materials allow some light to pass through.

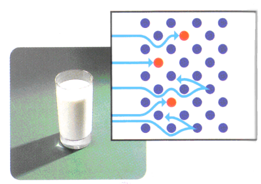


Figure 3
Opaque materials allow no light to pass through.

Classifying materials for transparency can be tricky. For example, a glass of water is transparent. However, you may have noticed that you cannot see the bottom of a deep lake, no matter how clear the water is. Water actually absorbs and reflects light slightly. As a result, small amounts of water are transparent, larger amounts are translucent, and very large amounts are opaque. This is true of all transparent materials. It is also true in reverse. If you cut an opaque material, such as a rock, into very thin slices, the slices will be translucent rather than opaque. Small amounts of an opaque material cannot absorb or reflect all the light.

296 Unit D Optics NEL

Figure 1. Example of the complementarity of words and pictures.[1] Without the three figures, the information contained in print is more difficult to understand.

[1] From *Nelson B.C. Science Probe 8 Student Text* by B. LeDrew, A. Carmichael, K. Farquhar, S. Marshall, J. Reid, & W. Shaw, 2006, Toronto, ON, Canada: Nelson Education Ltd. Copyright 2005 by Nelson Education Ltd. Reproduced by permission. www.cengage.com/permissions

Shen (1975) conceptualized science literacy as a triad of practical, civic, and cultural science literacy. He described practical science literacy as the "possession of the kind of scientific and technical knowledge that can be immediately put to use to help solve practical problems" (p. 27). Civic science literacy entailed an awareness of socioscientific issues that would "permit a fuller participation in the democratic processes of our technological society" (p. 28). Cultural science literacy addressed the understanding of science as a human endeavour. These three aspects have appeared in many subsequent efforts to define science literacy.

Focusing on students' actions in science classrooms, Westby and Torres-Valasquez (2000) also described three areas of science literacy, which they labelled knowing, doing, and talking. In their view, scientifically literate students would possess: a knowledge of science vocabulary and concepts; the ability to participate in science activities, including experiments and discussions; a knowledge of safe use of materials; the ability to work with other students; a familiarity with expository text structures; and an ability to describe, hypothesize, and deduce. Another definition can be found in British Columbia's Science Integrated Resource Package (Science IRP) for Kindergarten to Grade 7 (Ministry of Education, 2005), where scientific literacy is defined as "an evolving combination of the science-related attitudes, skills, and knowledge students need to develop inquiry, problem-solving, and decision making abilities; become lifelong learners; and maintain a sense of wonder about the world around them" (p. 11).

Despite their differences in defining the construct, many experts do agree that there are at least two dimensions to science literacy: producing and interpreting the discourses of science (fundamental dimension) and understanding the big ideas of science (derived dimension) (e.g., Norris & Phillips, 2003; Yore, Pimm, & Tuan, 2007). Fundamental aspects include the ways in which science learning is mediated, such as metacognition, language, and information communication technology (ICT), while derived aspects include disciplinary understandings, such as the big ideas and the nature of science (Figure 2). The two dimensions are interactive and symbiotic, with the development of aspects in one dimension affecting the development of aspects in the other dimension: the development of scientific knowledge is frequently enhanced by reading and communicated through writing. In addition, aspects in each of the two dimensions influence one another: metacognition influences language use when a writer thinks about how best to communicate a particular concept.

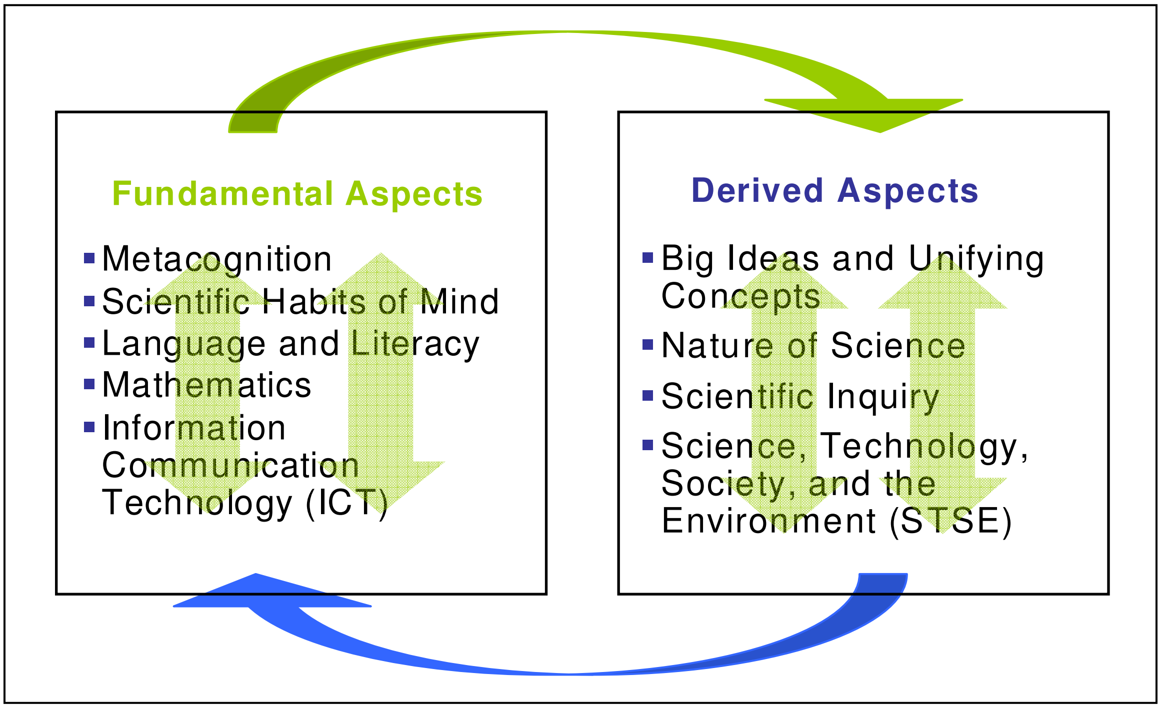


Figure 2. Interacting dimensions of scientific literacy (Yore, Pimm, & Tuan, 2007). Each aspect interacts with the other aspects in a particular dimension.

Language and literacy—a fundamental aspect of scientific literacy—provides a helpful basis for this discussion of visual literacy in science. In the following sections I describe current notions of language and literacy, provide an overview of language in the context of science, and highlight the importance of representational competence in science.

Language and Literacy

Any discussion of science literacy and scientific language should include an overview of literacy, since to be literate indicates some level of mastery in particular aspects of language. The construct of literacy has been evolving since the term was first introduced in the late 1800s (Willinsky, 1990). Literacy was initially considered the ability to read and write and the language arts consisted of two strands—reading and writing. Then, in response to sociopolitical changes, the notion of literacy expanded and the strands of listening and speaking were added. Next, there was a shift in standards of literacy away from decoding/analytic literacy, where the emphasis is on reading as a decoding skill, toward translation/critical literacy, where the emphasis is on negotiation of meaning (Myers, 1996). In addition, technological advances led to an even more complex notion of multiple literacies that encompasses static and dynamic images as well as words and includes working with sign systems such as maps and videotapes as well as writing (Anstey & Bull, 2006; New London Group, 1996). As the standard of literacy evolved from recitation to decoding to translation, and as dynamic images became more common, two more strands were acknowledged as important aspects of language and literacy—viewing and representing (Anstey & Bull, 2006; Myers, 1996). Although these two strands are the most recent additions to formal descriptions of language and literacy, they appear in the curriculum documents of every province and territory in Canada and of many American states (Begoray, 2000). These six strands of reading, writing, listening, speaking, viewing, and representing can be classified by function as interpreting or constructing, as shown in Figure 3, and have recently been recognized as playing essential roles in disciplinary literacy because their interaction contributes to the communication and construction of knowledge in the disciplines.

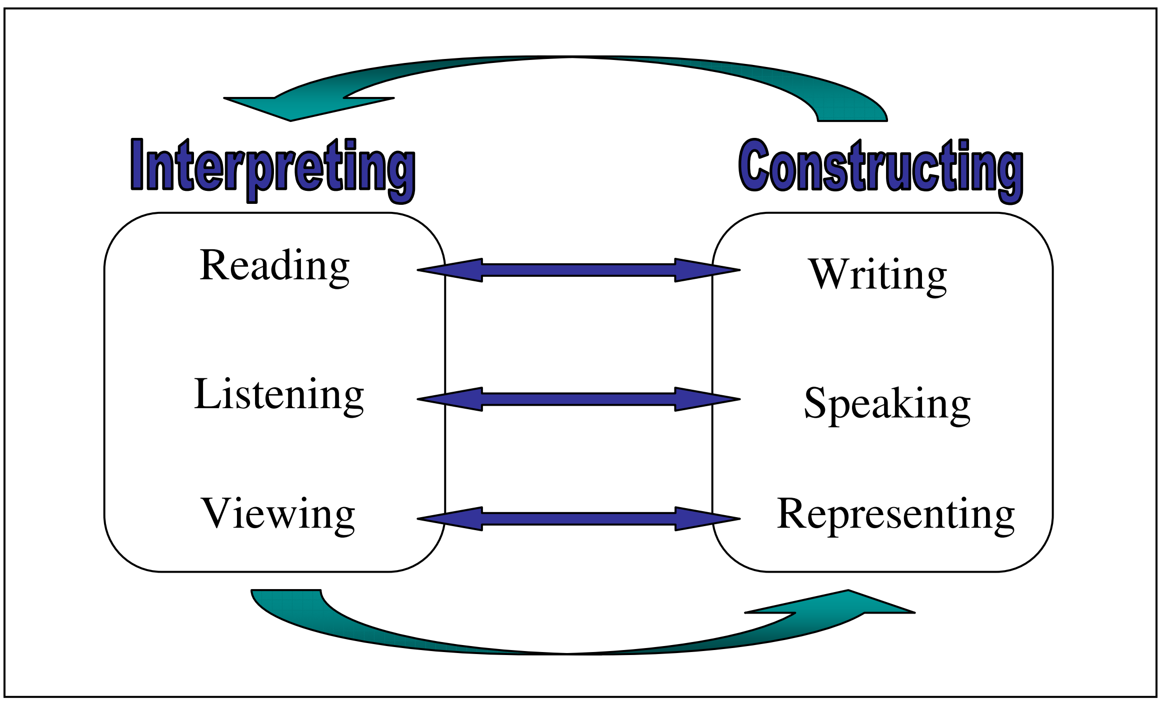


Figure 3. Six interacting strands of language and literacy (adapted from Tompkins, Bright, Pollard, & Winsor, 2008).

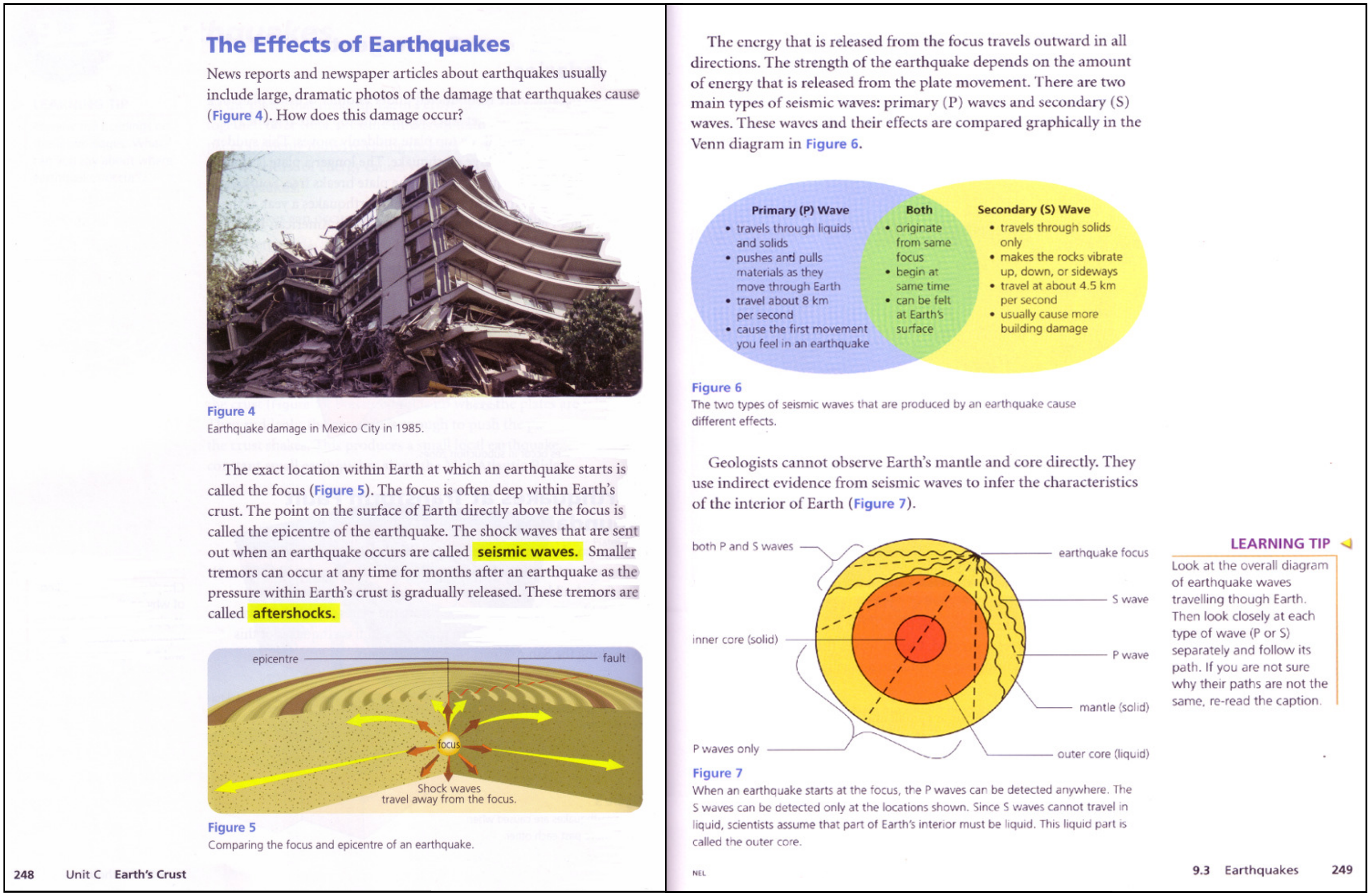
In British Columbia's English Language Arts Integrated Resource Package (Language Arts IRP) for Kindergarten to Grade 7 (Ministry of Education, 2006a), literacy is described as "the capacity to construct and express meaning through reading, writing, and talking about texts" (p. 16) and it "involves being able to understand and process oral, written, electronic, and multi-media forms of communication" (p. 3). Today, most texts comprise a combination of words, images, signs, and symbols; the importance of these latter visual elements is implied in this description of comprehension from the Language Arts IRP:

> Comprehension is the process of making meaning *with* and *from* text, whether the text is oral, written, visual, or multi-media [emphasis added]. This curriculum emphasizes the teaching of strategies that literate people use to make meaning as they speak, listen, read, view, write, and represent. These include both specific strategies to use when interacting with different kinds of text, and more general strategies for self-monitoring, self-correcting, reflecting, and goal-setting to improve learning. (p. 17)

The Language Arts IRP also states that "all teachers, at all grades, teaching all subjects, are teachers of literacy. Teachers do not just teach content knowledge but also ways of reading and writing specific to that subject area" (p. 33). Therefore, science teachers are expected to teach their students how to read and write in the context of their discipline. A specific science context calls for strategies that reflect the nature of the discipline, and those strategies are distinctly different from the strategies used when reading and writing narratives.

Literacy in the Context of Science

Reading like a scientist—reading the kinds of text that scientists read in the ways in which scientists would read them—involves drawing inferences from a variety of sign systems including print and images (Fang, 2005; Lemke, 1998). Scientific research articles typically contain titles, headings, figures, captions, tables, references, footnotes, and abstracts. Figures (visual representations) appear in a range of forms including photographs, diagrams, maps, and graphs. Children's science information text can be similarly complex, as shown in Figure 4, and print texts (textbooks and trade books) are the dominant source of science information in most classrooms (Yore, Craig, & Maguire,



The Effects of Earthquakes

News reports and newspaper articles about earthquakes usually include large, dramatic photos of the damage that earthquakes cause (Figure 4). How does this damage occur?

Figure 4
Earthquake damage in Mexico City in 1985.

The exact location within Earth at which an earthquake starts is called the focus (Figure 5). The focus is often deep within Earth's crust. The point on the surface of Earth directly above the focus is called the epicentre of the earthquake. The shock waves that are sent out when an earthquake occurs are called **seismic waves.** Smaller tremors can occur at any time for months after an earthquake as the pressure within Earth's crust is gradually released. These tremors are called **aftershocks.**

Figure 5
Comparing the focus and epicentre of an earthquake.

248 Unit C Earth's Crust

The energy that is released from the focus travels outward in all directions. The strength of the earthquake depends on the amount of energy that is released from the plate movement. There are two main types of seismic waves: primary (P) waves and secondary (S) waves. These waves and their effects are compared graphically in the Venn diagram in Figure 6.

Figure 6
The two types of seismic waves that are produced by an earthquake cause different effects.

Geologists cannot observe Earth's mantle and core directly. They use indirect evidence from seismic waves to infer the characteristics of the interior of Earth (Figure 7).

Figure 7
When an earthquake starts at the focus, the P waves can be detected anywhere. The S waves can be detected only at the locations shown. Since S waves cannot travel in liquid, scientists assume that part of Earth's interior must be liquid. This liquid part is called the outer core.

LEARNING TIP
Look at the overall diagram of earthquake waves travelling though Earth. Then look closely at each type of wave (P or S) separately and follow its path. If you are not sure why their paths are not the same, re-read the caption.

NEL 9.3 Earthquakes 249

Figure 4. Complexity of science information text. This double-page spread shows textual elements, including a title, multiple forms of diagrams, a photograph, captions, labels, bold font, and a sidebar.[2]

[2] From *Nelson B.C. Science 7 Student Text*, *1E,* by A. Chapman, D. Barnum, C. Dawkins, & W. Shaw, 2005, Toronto, ON, Canada: Nelson Education Ltd.

1998). Reading and writing in science is, therefore, more than reading and writing print; it is reading and writing information. As a result, literacy in the context of science includes interpreting and creating visual representations such as diagrams, graphs, maps, and charts (Moline, 1995; Norris & Phillips, 2003). As well, the process of creating visual representations can aid in the construction of understanding—a specific example of making meaning with text by writing-to-learn in science (Garcia-Mila, Andersen, & Rojo, 2010).

Fang and Schleppegrell (2010) note the unique nature of the language used in science texts, pointing out that vocabulary tends to be technical, abstract, and precise while sentences typically contain embedded clauses, noun phrases, and nominalizations. As a result, science concepts are often presented and described in compact and challenging passages. Additionally, science texts and textbooks are usually multimedia or multimodal presentations that contain both visual and verbal information in a range of formats and modes. Full comprehension of a text occurs only when readers are able to make meaning from each mode and are able to draw inferences based on the interaction of those modes and the relationships between the modes.

Disciplinary literacy is "an essential aspect of disciplinary practice, rather than a set of strategies or tools brought in to the discipline to improve reading and writing of subject matter texts" (Moje, 2008, p. 99). Disciplinary literacy includes using a range of representational modes (e.g., written and oral language, images, music, and gestures) to construct and communicate information, to synthesize ideas, and to formulate arguments. Science literacy encompasses specific ways of reading, writing, speaking, listening, viewing, and representing that are culturally mediated in the discourse community of science (Tang & Moje, 2010). For meaningful learning to occur, students must be aware of disciplinary conventions and understand how those conventions have been socially and culturally shaped (Moje, 2008).

A useful way of conceptualizing disciplinary literacy was proposed by Shanahan and Shanahan (2008). They differentiated among the highly generalizable, basic literacy practices that most students would be engaged in during the primary grades; the more sophisticated literacy practices—which are neither generic nor specific to a particular discipline but are useful depending upon context—that are typically acquired during the intermediate and middle grades; and the highly specialized literacy practices—which tend to be highly technical, not widely generalizable, and reflect the discipline within which students are constructing meaning—that occur during high school and university. The use of representations in science would emerge as a focus in the intermediate literacy stage and would be a critical aspect of disciplinary literacy. These three clusters of literacy practices are shown in Figure 5. It should be noted that learning would require movement up and down the steps as students develop new literacy practices and utilize others that have already been mastered; in addition, mastery of a specific practice in one stage does not mean mastery of all practices in that stage.

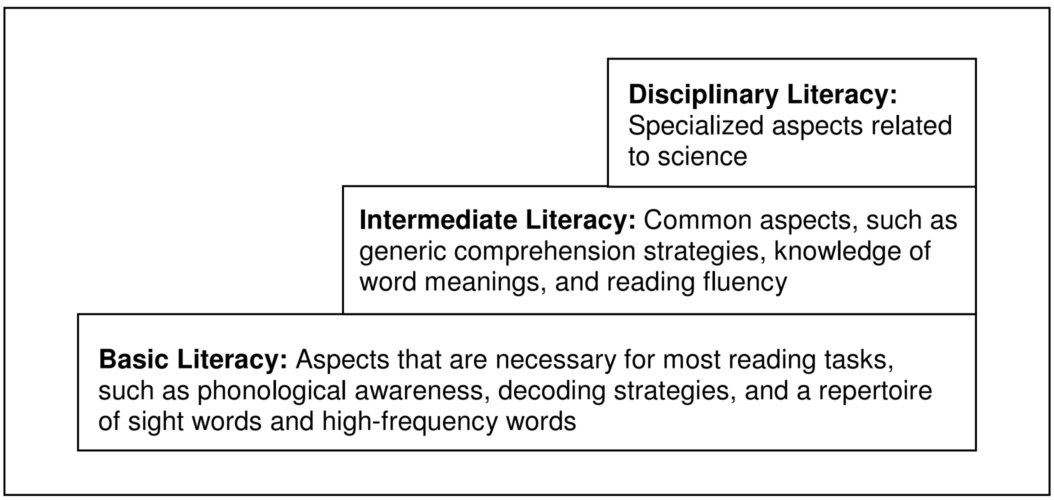


Figure 5. Three stages of literacy development (adapted from Shanahan & Shanahan, 2008, p. 44). Each step is progressively smaller, reflecting the generalizability of the aspects, and the height of the steps reflects the level of specificity of the aspects.

Science is a social and cultural endeavour, and the construction of scientific knowledge is also mediated by social interactions that are embedded in the particular discourses of science—or Discourses with a capital D, in accordance with Gee’s (2005) usage of the term to indicate the cultural aspects of ways of knowing within a particular community. Moje, Collazo, Carrillo, and Marx (2001) presented writing as an aspect of discourse, while knowing how to differentiate between writing a technical science report and writing an opinion piece on a scientific issue would be an aspect of science Discourse. Writing a personal letter or an opinion-based editorial would be situated in the basic and intermediate stages of literacy development; writing a technical science report would be an aspect of disciplinary literacy.

Reading, writing, listening, speaking, viewing, and representing are not merely tools to be used in the acquisition and communication of scientific knowledge, however. From a systemic functional linguistics (SFL) perspective, science is shaped by the language that scientists choose to use and the language that scientists use is, in turn, shaped by the specialized demands of communicating science (Fang, 2005; Fang & Schleppegrell, 2010; Halliday & Martin, 1993; Yore, Florence, Pearson, & Weaver, 2006; Yore, Hand, & Florence, 2004). The language of science construes meaning and through that construal has developed unique grammatical and textual features, such as high levels of lexical density (the amount of information contained in a text), abstraction, and technicality (the use of specialized terminology), and the frequent use of visual representations (Fang, 2005; Halliday, 2004; Trumbo, 2000; Unsworth, 2001). The iconic and indexical properties of visual representations, discussed in more detail in Chapter 3, allow information to be communicated with a precision and convenience unequalled by the properties of written or oral language (Huxford, 2001). Much scientific knowledge has developed through the use of detailed visual representations; for example, Leonardo da Vinci filled his now-famous notebooks with intricate drawings that captured his observations of the natural world and enabled him to conceptualize his understandings (Trumbo, 1999).

Theoretical Foundations: Constructivist Principles of Learning

Visual literacy and multiple representations are fairly recent areas of science education research, beginning in the late 1970s or early 1980s (Myers, 1988). As a result, most of the research has been based in a constructivist framework (e.g., Mayer, 2001, 2005c). This dissertation was designed with constructivist principles providing the theoretical foundations.

The main tenet of constructivism is that meaning is actively constructed as a learner interprets events through the lens of prior knowledge. Cognitive constructivism, which is based on the work of Piaget (Bringuier, 1980; Piaget, 1977), emphasizes that knowledge is built through personal experience. Other constructivist perspectives include social constructivism, which is based on the work of Vygotsky (1934/1986) and emphasizes the social nature of experience, and interactive-constructivism, which is a hybrid perspective on learning in which knowledge construction may be an individual or a group process with the results of that process judged according to currently accepted scientific data, laws, and theories (Yore, 2001). According to the interactive-constructive perspective, pedagogical content knowledge, accountability, and school priorities play a role in establishing a learning environment and the responsibility for learning is shared by the individual and the classroom community.

All components of the dissertation were situated within a constructivist framework. The literature review in Chapter 2 consists of a body of work that is almost exclusively constructivist. The exploratory framework that is proposed in Chapter 3 includes the Peircian (1986) notion that the interpretation of a sign results in the construction of a new sign, depending upon the prior knowledge of the interpreter. The interactive-constructive perspective was foundational in the design and development of the larger community-based project within which the dissertation was situated; therefore, the case studies described in the case-to-case synthesis in Chapter 4 were influenced by that perspective. Finally, the verification study described in Chapters 5 and 6 was designed and implemented from an interactive-constructive perspective. Students read unfamiliar science information text passages and independently created visual representations based upon those passages. More importantly, however, students used their prior knowledge and previous experiences to create the visual representations, a process that required active construction of concepts and ideas. In addition, the social negotiations that typically occurred in the middle school science classrooms where my research was conducted are assumed to have influenced the artefacts that students produced and described.

Much of the recent research on visual representations in science also adheres to the following three principles of learning (USNRC, 2005):

- All students have preconceptions that must be acknowledged if learning is to occur in a meaningful manner.
- Competency (literacy) in a subject requires factual knowledge organized in a conceptual framework that supports retrieval and application of that knowledge.

- Metacognitive skills help students to monitor their learning and to apply strategies to facilitate learning.

These three principles are compatible with cognitive and constructivist theories of learning, which dominate current thinking about how people learn science (e.g., Muller, Sharma, & Reimann, 2008; USNRC, 1996, 2005.

Research Questions

The dissertation research consisted of three separate yet related endeavours. One aspect was the development of a theoretical framework that could be used to explain students' interpretation and construction of static or dynamic visual representations. The second aspect was a metasynthesis of my previous work in the area of visual literacy and multiple representations. The third aspect was a mixed-methods investigation focusing on middle school students' representational competence. A separate question guided each aspect of the dissertation research.

The question guiding the development of the theoretical framework was: *What are the key dimensions of an encompassing framework for learning with visual representations as indicated by a review of relevant literature, and how might those dimensions be related?* The question guiding the metasynthesis was: *What common themes emerge from previous Pacific CRYSTAL case studies, and how might these themes relate to the exploratory framework?* The question guiding the classroom-based investigation undertaken in the 2009–2010 school year was: *What happens when students in Grade 6 are asked to construct visual representations based on unfamiliar science information text, and how do these results relate to the exploratory framework?*

Limitations of the Study

The body of representational competence and visual literacy literature is small, though growing. The lack of a substantial number of studies limits the potential for conducting a metasynthesis that would have widespread implications. However, I conducted a metasynthesis of my own related research projects as part of the development and application of the preliminary theoretical framework. This case-to-case synthesis helped to establish a lens for the classroom observations.

The verification study described in this dissertation was designed to investigate middle school students' use of diagrams. However, the small number of participants imposes a significant limitation. In addition, participants were volunteers and, therefore, were not randomly selected; and all participants were from the same small school district. Thus, the results of the verification study have limited generalizability. The results do, however, provide insights about middle school students' representational competence and will serve as a basis for future research.

The dissertation focused on students' use of diagrams in order to restrict the larger problem space encompassing students' use of all representations. Explanatory diagrams were the most scientifically appropriate way to represent the information that was given to students although students were not restricted in any way. In addition, aspects of representational competence, such as locating information and use of arrows, were examined with the use of multimedia text containing diagrams. This narrow focus strengthens the findings with respect to diagrams but limits the findings with respect to visual representations in general.

Implications of the Research

The research described in this dissertation is likely to make a contribution to the body of visual representation research in science education. While much research on visual representations has been conducted outside of school settings and has been based on dual-coding models (e.g., Paivio, 1991) of information acquisition from existing texts, my research was conducted in regular middle school classrooms; therefore, I examined the creation and interpretation of scientific diagrams in an authentic learning environment. Typical participants in published multiple representation and multimedia research are undergraduate or high school students; this study involved participants who were in middle school, thus revealing insights into younger students' visual literacy. Finally, a major component of the dissertation was the development of an integrated theoretical framework that could be used to guide future classroom-based research in visual representations.

Organization of the Dissertation

The dissertation consists of seven chapters. In this chapter, I began with a rationale for undertaking the dissertation research. The overarching constructivist framework for the dissertation was described, and a context was provided by situating visual literacy and representational competence within science literacy. The questions guiding the program of research were outlined and the potential limitations and implications of the study were listed.

In Chapter 2, I provide working definitions for the terms that are used in the dissertation, which are followed by a brief description of visual literacy and representational competence. The literature on multiple representations, multimodal research, and multimedia research is reviewed; and the results of relevant recent research are summarized. The cognitive models upon which most of the relevant research on learning *from* multimedia or multimodal science texts has been based are also presented in Chapter 2.

I describe the development of a proposed theoretical framework in Chapter 3. This exploratory framework is multidimensional, reflecting the nature of current science pedagogy. If results indicate that it is valid, the framework could be used to support future research in learning *with* as well as *from* multimedia and multimodal science texts.

The relevant research that I previously conducted as part of the *Pacific CRYSTAL: Explicit Literacy Instruction Embedded in Middle School Science* project is summarized and synthesized in Chapter 4. This research includes several case studies examining students' use of informational brochures, informational posters, and Foldables® to demonstrate understanding of science concepts.

The mixed-methods research approach is presented in Chapter 5. In this chapter, I also outline the specific qualitative and quantitative approaches that I followed in the verification study.

In Chapter 6, the results of the verification study are presented. The insights and indications that were revealed by examining and synthesizing qualitative and quantitative data collected during the verification study are discussed.

I provide a summary of the dissertation and its components in Chapter 7. Potential implications for teachers, curriculum developers, and publishers are discussed. The chapter, and the dissertation, concludes with recommendations for future research. The connections between the literature review and the three components of the dissertation are shown in Figure 6. The literature review influenced the development of the exploratory framework (a), which influenced the case-to-case synthesis (b). The results of the case-to-case synthesis influenced the exploratory framework (c). The results of the case-to-case synthesis, in combination with the literature review and the exploratory framework, influenced the design, implementation, and analysis of the verification study (d). Finally, the results of the verification study were used to examine the exploratory framework.

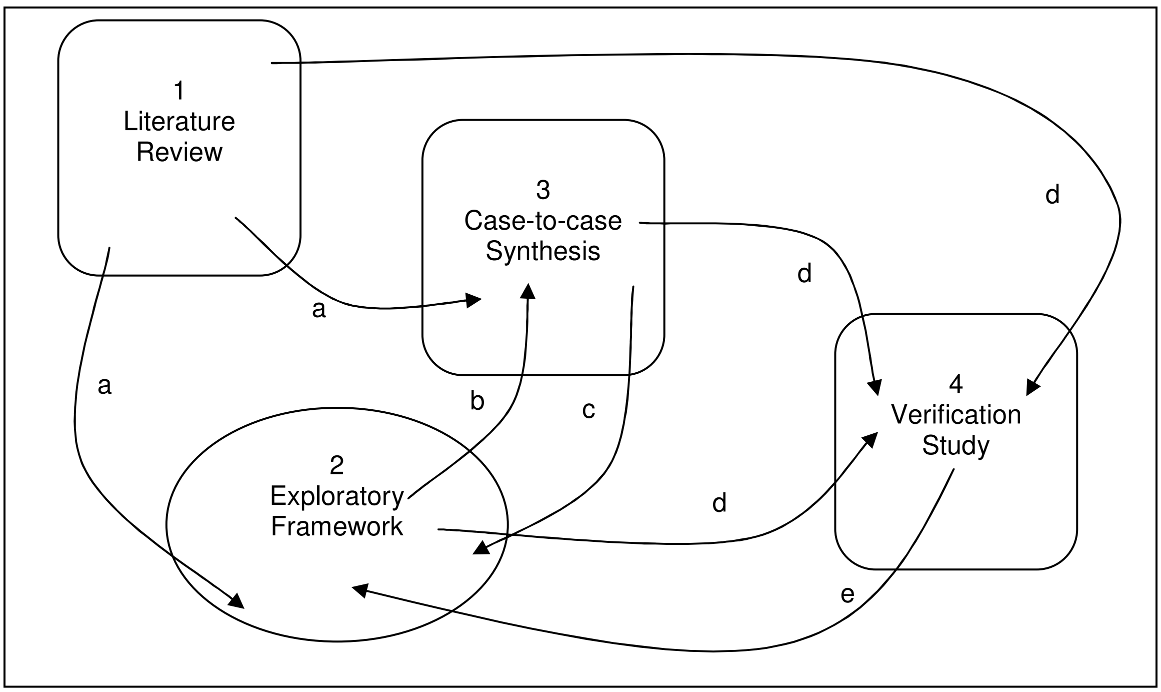


Figure 6. Connections between the literature review and the three components of the dissertation.

Chapter 2
Literature Review

In this chapter, I describe the context for the dissertation and develop operational definitions for key constructs and terms. I summarize theories for learning from representations and then present a thematic review of current research on the use of representations in science. I conclude the chapter with a brief discussion of the benefits and challenges of learning with visual representations.

The problem space within which the dissertation is situated includes aspects that are fairly well-defined (learning *from* multimedia texts) and other aspects that are less well-delineated (learning *with* multimedia text). The problem space is also located at the intersection of three areas of research in science: multiple representations research, multimedia research, and multimodal research, as shown in Figure 7.

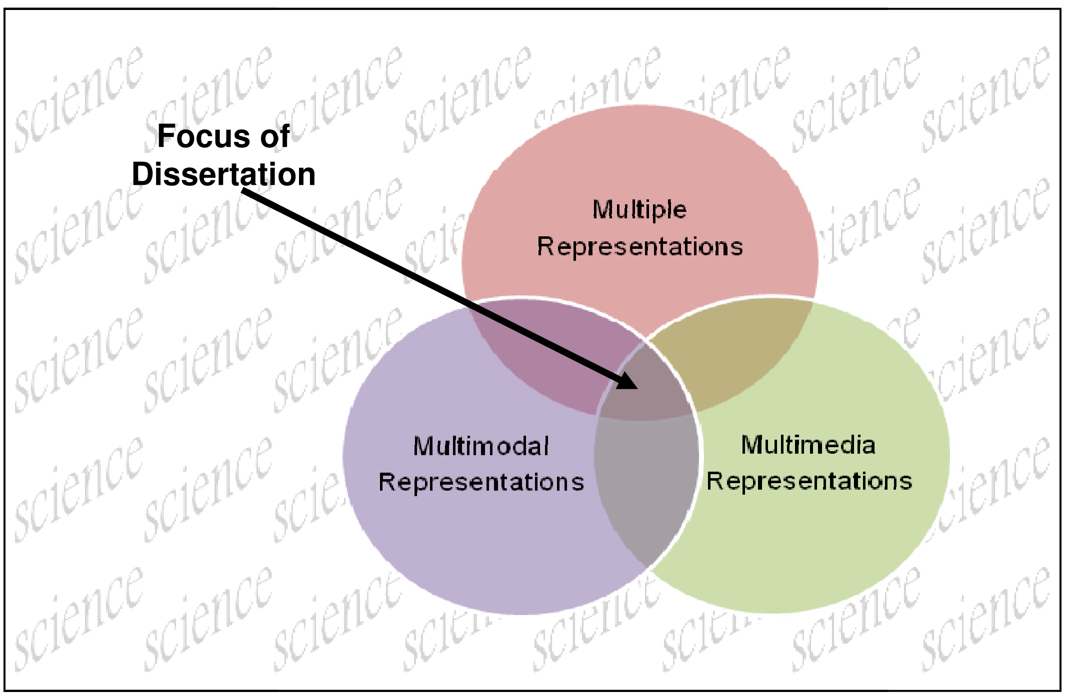


Figure 7. Overlap of multiple representation, multimedia representation, and multimodal representation research in the context of science.

Multiple representation research investigates the use of more than one representation at a time, but those representations could all be in a single sensory mode (e.g., visual representations in the form of words, pictures, and symbols) as is the case with this dissertation research, or in multiple sensory modes (e.g., spoken words, printed images, and a hands-on demonstration). Multimodal research might examine the use of multiple sensory modes (e.g., combining dramatic activities, a song containing the science concepts, and reading a science information text) or the use of multiple presentation modes (e.g., verbal and nonverbal) as is the case with the dissertation research. Multimedia research might explore the use of multimedia technology (e.g., animations, video streaming, or computer games) or any combination of words and pictures regardless of the mode of combination (e.g., a print source containing written words and visual representations, a PowerPoint presentation of images accompanied by an audio narration, or a computer game with animations and audio instructions). The dissertation research is an investigation of multimedia science information text based on printed words and images, and it could also be considered an examination of multimodal (visual and verbal) multiple representations (print and picture).

The multifaceted nature of the problem space is reflected in the variety of terms that appear in the relevant literature and in the multiple ways in which those terms are used. Therefore, the first section of this chapter consists of an overview of relevant terms and constructs that is intended to provide a consistent starting point for the literature review. In the second section, recent literature from the areas of multiple representations research, multimedia research, and multimodal research is reviewed. In the third section, the three cognitive models of learning from multimedia and multimodal science text, upon which most of the recent research has been based, are presented.

Constructs and Terms

Although visual literacy was discussed in Chapter 1, the overview of constructs and terms begins with a discussion of the many definitions that have been formulated for this construct. Operational definitions for representational competence, levels of representations, diagrams, multimedia, and multimodality are also provided in this section.

Visual Literacy

Visual literacy is an interdisciplinary construct that is influenced by theory and practice from a range of fields including art, computer science, cultural anthropology, education, graphic art, instructional design, linguistics, neurophysiology, philosophy, psychology, screen education, semantics, semiotics, sociology, and visual perception (Aanstoos, 2003; Avgerinou & Ericson, 1997; Debes, 1969). It is hardly surprising that with such diverse influences visual literacy has remained an ill-defined construct since Debes (1969) first described it as “a great amoeba-like entity with pseudopods reaching out in many directions” (p. 25). Definitions of visual literacy, spanning four decades, are shown in Table 1.

Table 1

Definitions of Visual Literacy from 1969 to 2010

Debes (1969, p. 27):
Visual literacy refers to a group of vision-competencies a human being can develop by seeing and at the same time having and integrating other sensory experiences. The development of these competencies is fundamental to normal human learning. When developed, they enable a visually literate person to discriminate and interpret the visible actions, objects, symbols, natural or man-made, that he encounters in his environment. Through the creative use of these competencies, he is able to communicate with others.

Bamford (2003, p. 1):
Visual literacy involves developing the set of skills needed to be able to interpret the content of visual images, examine social impact of those images and to discuss purpose, audience and ownership. It includes the ability to visualise internally, communicate visually and read and interpret visual images. In addition, students need to be aware of the manipulative uses and ideological implications of images. Visual literacy also involves **making judgements** [bold in original] of the accuracy, validity and worth of images. A visually literate person is able to discriminate and make sense of visual objects and images; create visuals; comprehend and appreciate the visuals created by others; and visualize objects in their mind’s eye. To be an effective communicator in today’s world, a person needs to be able to interpret, create and select images to convey a range of meanings.

Black Cockatoo Publishing (2006):
If you can read a map, draw a diagram or interpret symbols like  or  then you are visually literate. Visual literacy is the reading and writing of visual texts.

Felton (2008, p. 60):
Visual literacy involves the ability to understand, produce, and use culturally significant images, objects, and visible actions

International Visual Literacy Association (IVLA, 2010):
Each visual literacist has produced his/her own [definition]! Understandably, the coexistence of so many disciplines that lie at the foundation of the concept of Visual Literacy, thus causing and at the same time emphasizing the eclectic nature of it, is the major obstacle towards a unanimously agreed definition of the term.

Representational Competence: An Aspect of Visual Literacy

Representational competence is a specific aspect of the much broader construct of visual literacy. In the context of science, representational competence is the set of skills and practices associated with the use of a variety of visual representations to think, communicate, and conceptualize about science concepts (Kozma & Russell, 2005b). These abilities include understanding the conventions for a range of representations and knowing how each form can and cannot be used, identifying and analyzing particular features of representations, transforming and mapping between representations, creating or selecting an appropriate representation for a specific purpose, evaluating representations and justifying the appropriateness of a particular representation, inventing new representations, comparing and contrasting information obtained from different representations, solving problems using representations, and using representations to support claims, make inferences, and make predictions (diSessa, 2004; Gilbert, 2008; Kozma & Russell, 2005b; Wilder & Brinkerhoff, 2007). Representational competence when learning from diagrams involves understanding the interrelationship between diagrams and the print information within which they are typically embedded (Gilbert, 2008).

Representational competence can be viewed as a progression from novice to expert use of representations. Kozma and Russell (2005b) proposed five levels of development (see Table 2), noting that progression from one level to another might be neither automatic nor uniform. Rather, increasing mastery would depend upon progressive use of representations and on the context of that use. The levels of representational competence include both the interpretation and creation of representations. The term *metarepresentational competence* has been used to distinguish between rote memorization of a canon of scientific representations and the much more complex and creative ways in which scientists of all ages work with representations (diSessa, 2004; diSessa & Sherin, 2000). Metarepresentational competence can also be used to differentiate between what students can do *with* representations and what students know *about* representations (Kohl & Finkelstein, 2005a). diSessa and Sherin (2000) pointed out that the 'meta' in metarepresentational was not meant to suggest metacognition but that there are similarities between the two constructs. Metacognition involves metacognitive awareness (declarative, procedural, and conditional knowledge) and executive control (planning, monitoring, and regulating)—aspects of which are clearly evident in the upper levels of representational competence (e.g., reflective use of representations).

Table 2

Levels of Representational Competence (from Kozma & Russell, 2005b, p. 133)

Level 1: Representation as Depiction When asked to represent a physical phenomenon, the person generates representations based only on physical features. The representations are iconic depictions of the phenomenon at a single point in time.
Level 2: Early Symbolic Skills When asked to represent a physical phenomenon, the person generates representations based on physical features and includes some symbolic elements such as arrows in order to capture time or motion. There is no obvious formal use of syntax or semantics.
Level 3: Syntactic Use of Formal Representations When asked to represent a physical phenomenon, the person generates representations based on observed physical features and unobserved causes. The representational system may be invented but focuses on syntax of use rather than the meaning of the representation. A comparison of representations is based on shared surface features or syntactic rules rather than on a shared underlying meaning.
Level 4: Semantic Use of Formal Representations When asked to represent a physical phenomenon, the person uses a formal symbol system to represent physical features and unobservable entities and processes. This formal system is based on syntactic rules and on meaning. Comparisons between representations are based on shared meanings. The person can transform representations and spontaneously uses representations to solve problems or make predictions.
Level 5: Reflective, Rhetorical Use of Representations When asked to explain a physical phenomenon, the person uses one or more representations based on physical features and unobservable entities and processes. Specific aspects of a representation can be used in a rhetorical context, for example, to warrant claims. The person can select the most appropriate representation for a particular situation and justify that selection. The person knows that we cannot directly experience certain phenomena, which are understood only through their representations, and thus this understanding is open to interpretation.

Diagrams

Being able to create and interpret diagrams requires knowledge of the conventions of sequence and pattern, an aspect of representational competence. When interpreting diagrams, understanding the relationship between diagrams and the print information within which they are embedded is also considered an aspect of representational competence (Gilbert, 2007, 2008). Novick (2006) noted that knowledge of the conventions of diagrams and of the domain being represented by the diagram are both necessary for diagrammatic competence.

Diagrams are a graphic format for conveying information about processes and structures. The continuum of representations can be considered to extend from words (highly abstract) to unretouched photographs (highly realistic), with diagrams typically falling somewhere between these two extremes (Winn, 1987). Diagrams can be used as scaffolds for knowledge construction, aids to memory, and tools for instruction (Richards, 2002). Diagrams appear frequently in children's science information text; an analysis by Unsworth (2004) revealed that diagrams were the most common type of visual representation used in the elementary trade books, secondary textbooks, CDs, and websites that were examined. The function of diagrams is primarily informative—a characteristic that distinguishes diagrams from other visual representations, such as drawings and images (Amare & Manning, 2007).

Diagrams consist of connected nodes or elements, where the nodes might be pictures, icons, or symbols and the connections might be spatial, temporal, or propositional (Gilbert, 2007). Sequences and patterns are important aspects of diagrams (Winn, 1987). Diagrams often indicate sequences by following conventions of print information, for example, top left to bottom right. Links between elements, such as numbers or arrows, can also indicate sequence. Diagrams may convey meaning through patterns of nodes; for example, a hierarchy can be indicated using boxes, spatial positioning, and linking lines.

Diagrams are based on a relatively relaxed system of rules compared to restrictive and rigid systems such as algebraic functions, the alphabet, chemical equations, or musical notation (Pérez Echeverría & Sheuer, 2010). However, these rules do provide some conventions, which in turn create a structure for interpreting and communicating. Much like languages have attendant rules of grammar, a grammar for visual images has been proposed (Kress & van Leeuwen, 2006). This grammar is discussed in more detail in Chapter 3.

The dissertation research focused on diagrams that represented systems, processes, or structures in science. This type of diagram, sometimes called an explanatory diagram, can also be used to construct, explain, and communicate information about instructions, procedures, sequences, principles, ideas, events, and behaviours (Breckon, Jones, & Moorhouse, 1987).

Levels of Representations

Visual representations such as diagrams are ubiquitous in science because they are used both to communicate and to construct knowledge about phenomena. Visual representations range from symbols and equations to three-dimensional models, animations, and simulations, and are typically classified by level of the phenomena represented. There are three levels of representations described in the literature: symbolic (e.g., algebraic equations, formulae, and some iconic representations), submicroscopic (e.g., bonds at the particulate or molecular level), and macroscopic (e.g., depictions of concrete or tangible items and experiences) (Gilbert, Reiner, & Nakhleh, 2008). Switching between levels and understanding the conventions of each level requires a high degree of representational competence (Gilbert, 2007). Interestingly, there does not seem to be a category for representations of structures and functions that are *larger* than what can be easily seen or imagined, such as the parts of the sun or the layers of the Earth's atmosphere, which were two of the topics that were the focus of investigation in the dissertation research.

Multimedia

Science texts typically contain both verbal and visual components and, accordingly, have been described as multimedia texts. The term *multimedia* can mean an audiovisual presentation, such as a presentation projected on a screen and accompanied by music. Mayer (2001, 2005b) suggested that multimedia be used to indicate a combination of words and pictures, regardless of how those words and pictures are presented. A multimedia representation could include a computer program with animated graphics accompanied by an audio feed, a lecture during which illustrations are shown using a slide or overhead projector, and a textbook with printed information accompanied by visual representations. Using this meaning, which was based upon research in cognitive psychology, learning with multimedia can be considered dual-code or dual-channel learning. In this context, the dissertation research can be considered multimedia since I explored students' use of text comprised of verbal and pictorial information.

Four principles have emerged from several decades of research examining learning from multimedia texts: the multimedia principle, the split-attention principle, the coherence principle, and the redundancy principle. These four principles primarily refer to explanatory multimedia documents; in other words, documents that explain systems or processes and are based upon extensive research (Mayer, 2001).

The multimedia principle states that learning can be enhanced when information is presented in two forms, particularly when pictures are added to words (Fletcher & Tobias, 2005; Mayer, 2001). Multimedia representations may lead to increased retention of information and to increased transfer of information during subsequent problem solving (Mayer, 2001). Not all multimedia representations are equally effective because the task, context, and form of the presentation all have an effect on learning.

The split-attention principle states that learning can be negatively affected if sources of information are not integrated spatially and temporally (Ayres & Sweller, 2005). Cognitive load is increased when learners need to mentally integrate information from different sources, and an increase in cognitive load tends to have a negative effect on learning (Ayres & Sweller, 2005). The split-attention principle is based upon the spatial contiguity and the temporal contiguity principles. The spatial contiguity principle states that learning is enhanced when corresponding words and pictures are located near each other; the temporal contiguity principle states that students learn better if words and pictures are presented simultaneously rather than sequentially (Mayer, 2001). The term *attentional switching* is sometimes used to avoid the implication of parallel processing (Hyönä, 2010).

The coherence principle states that learning is enhanced if extraneous information is excluded (Mayer, 2001). Ways to increase coherence include eliminating interesting but irrelevant details in words and pictures (Mayer, 2005c).

The redundancy principle states that when identical information is presented in multiple forms learning can be negatively affected (Sweller, 2005). An example of redundant presentation would be a visual representation and a printed passage accompanied by an identical audio track (Mayer, 2001). This principle should not be confused with multiple representations, which typically contain similar but not identical information.

Multimodality

Texts that are multimedia may also be considered to be multimodal. Modes are sometimes defined as sensory modes: sight, hearing, touch, smell, and taste; a multimodal experience would involve more than one of the senses (Mayer, 2005a). However, modes are more often thought of as specific ways to achieve "complex representational and communicational requirements and tasks" (Kress, 2010, p. 28) or sign systems that are "organized sets of semiotic resources for meaning making" (Jewitt, 2008, p. 246). Speech, static images, animated images, gestures, music, writing, three-dimensional (3D) models, color, and even layout could be considered modes because each category consists of distinctive organizational structures that can convey culturally derived meanings (Kress, 2010; Siegel, 1995). Each mode has a range of affordances for communicating and constructing meaning. Unsworth (2004) noted that most texts are inherently multimodal, with combinations of linguistic and graphic modes, and that science texts are no exception.

Within the specific context of using representations to communicate information, modality can be considered one of several characteristics of representations, along with perspective, precision, specificity, and complexity (Table 3, de Jong et al., 1998). The mode is the particular form that is used to display information and can include text (written information), animations, diagrams, graphs, algebraic notations, video, formulae, and tables. Using this definition, the modes in the verification study would be written information and diagrams; therefore, the dissertation research can be considered multimodal as well as multimedia.

Cognitive Theories and Models of Learning from Visual Representations

While it is widely accepted that visual representations play a role in learning, communicating, and thinking in science (e.g., Lemke, 1998; Schnotz, 2002), there is a lack of consensus regarding the cognitive processes involved in interpreting those visual representations. A number of different cognitive theories and models have been described in the multiple representation/multimedia/multimodal literature. In the following sections, I present the three theories and models that appear most frequently: Dual Coding Theory (Paivio, 1991; Sadoski & Paivio, 2001), the cognitive theory of multimedia learning

(Mayer, 2005a; Mayer, Bove, Bryman, Mars, & Tapangco, 1996), and an integrated model of text and picture comprehension (Schnotz, 2002, 2005).

Table 3

Dimensions of Representations Used to Display Information (adapted from de Jong et al., 1998)

Dimension	Description
Perspective	The theoretical viewpoint taken when presenting information, such as function or behaviour. Perspective is influenced by decisions about what information to include and how to include it.
Precision	The level of accuracy of the information presented; occasionally a matter of qualitative versus quantitative information.
Specificity	The economical representation of information which is facilitated when highly specific representations have focused or restricted interpretations.
Complexity	The amount of information presented, where amount refers to types of information rather than quantity.
Modality	The form of expression used for displaying information, mode can include propositional and figural presentations.

Dual Coding Theory.

Most early studies on the interpretation and comprehension of information contained in visual representations were based upon Paivio's (1991) Dual Coding Theory (DCT; Schnotz, 2002). DCT is a cognitive theory that predicts two different systems of mental representation: one for language and another for nonverbal objects (Sadoski & Paivio, 2001). The two representation processing systems, or coding systems, may work independently, in parallel, or together, depending on the task and the connectedness of the text being processed. According to DCT, concepts presented through a combination of pictures and words will be learned and remembered more effectively than concepts presented through words alone. Figure 8 is a representation of the verbal and nonverbal coding systems and the connections that may exist between them.

The cognitive theory of multimedia learning.

Mayer et al. (1996) proposed a cognitive theory of learning from multimedia that was derived from theories of dual coding (Paivio, 1991), cognitive load (e.g., Sweller & Chandler, 1991), and generative learning (e.g., Wittrock, 2010). Cognitive load

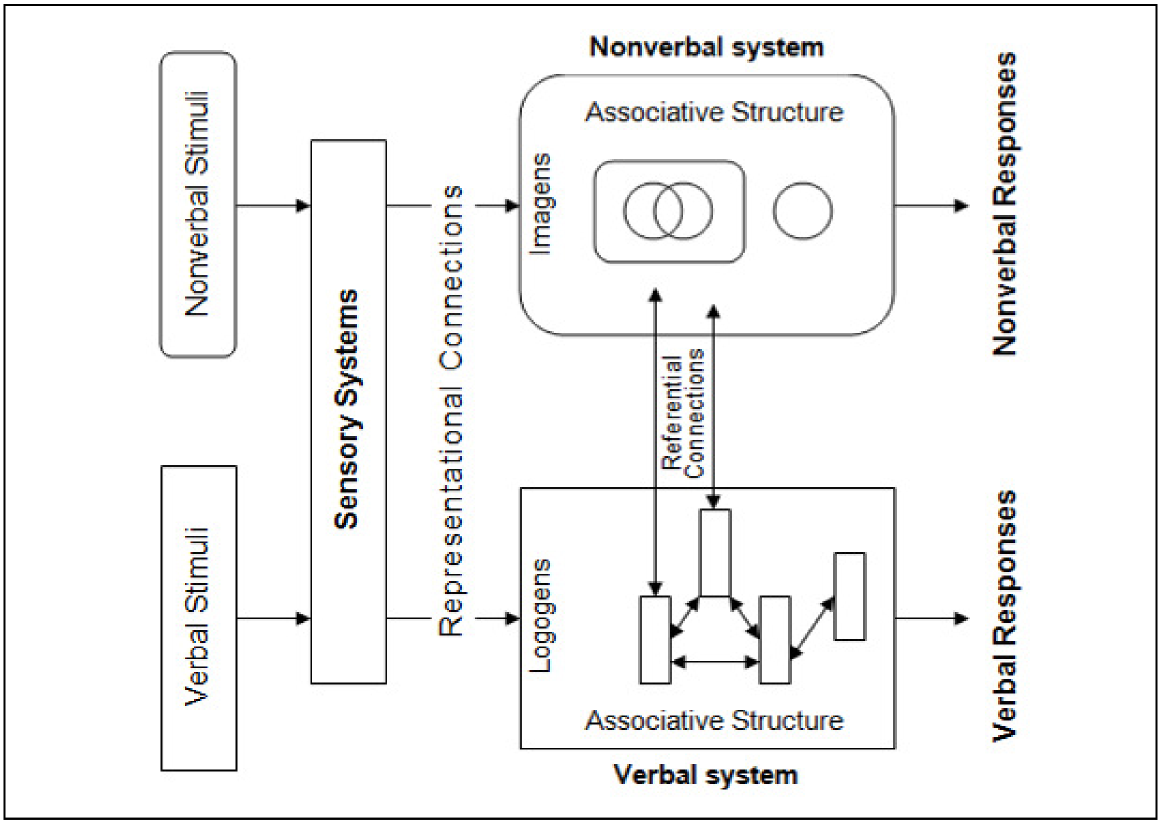


Figure 8. A representation of DCT (redrawn from Sadoski & Paivio, 2001, p. 53).

theory is based on models of working memory (e.g., Baddeley & Hitch, 1977; Miller, 1994), which refer to the brain system that stores and manipulates information during complex cognitive tasks such as language comprehension and learning (Baddeley, 1992). The working memory is thought to consist of three components: a central executive, which is an attention-controlling system, and two slave systems, a visuospatial sketch pad that manipulates visual images and a phonological loop that stores and rehearses speech-based information. Cognitive load theory suggests that people possess finite cognitive resources that can be accessed when constructing meaning, and research has indicated that the working memory is capable of handling seven plus or minus two pieces of information (Miller, 1994).

Generative learning theory is based on the principle that people tend to generate meanings that are consistent with their prior knowledge and experiences (Wittrock, 2010). This theory predicts that learners generate associations between prior experiences, which are stored in long-term memory, and new events, which act as stimuli. Sometimes the cognitive theory of multimedia learning (CTML) is referred to as the generative theory of learning, a name intended to emphasize its three underlying aspects: dual channels, limited capacity, and active processing (Mayer, 2005a). However, Mayer and colleagues selected CTML as the name to be used in their recent publications and for use in major reviews.

According to CTML, meaningful learning involves five cognitive processes: word selection, image selection, word organization, image organization, and the integration of words and images. CTML predicts that verbal working memory and visual working memory are both utilized during learning—similar to DCT that predicts the involvement of verbal and nonverbal systems and their associative structures. CTML differs from DCT, however, in that verbal and visual systems are thought to work in parallel to produce two types of mental representations that are then integrated with one another (Mayer, 2005a). Learning from multimedia promotes knowledge construction rather than memorization of information because learners build their own internal representations when processing multiple presentations and learners are engaged in sense-making rather than in rote memorization (Mayer, 2001). The cognitive theory of multimedia learning is illustrated in Figure 9.

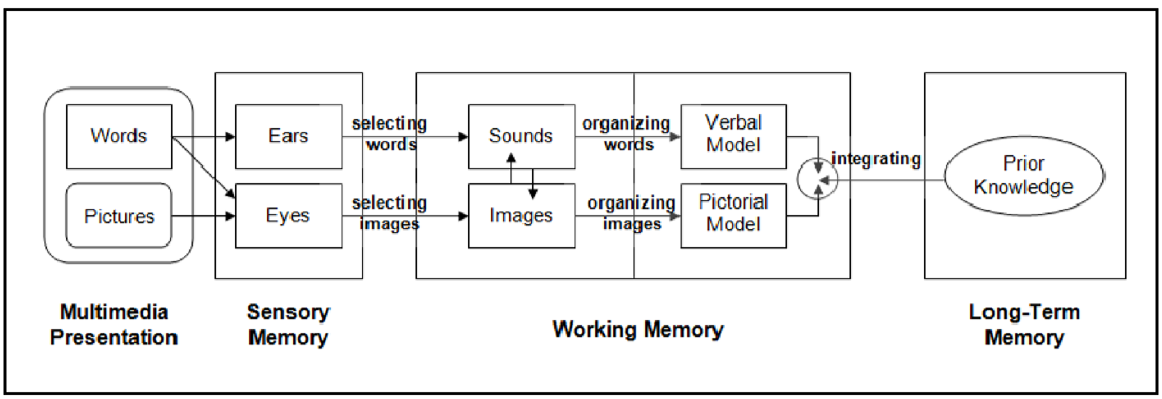


Figure 9. A representation of the cognitive theory of multimedia learning (redrawn from Mayer, 2005a, p. 37).

An integrative model of multimodal comprehension.

Schnotz (2002) proposed an integrative model of multimodal comprehension (IMMC). The IMMC, shown in Figure 10, emphasizes mental representations of multimodal texts, and like DCT and CTML, predicts the involvement of visual and verbal processing systems. Because there are interactions between words and pictures, there is not an exact one-to-one correspondence between internal and external representations: both words and visuals can lead to either descriptive (verbal) or depictive (pictorial) mental representations. IMMC differs from DCT in that the construction of mental representations is depicted as a more elaborate process than simply a second coding of information. Both CTML and IMMC draw on models of working memory (e.g., Baddeley & Hitch, 1977) and generative learning (e.g., Wittrock, 2010).

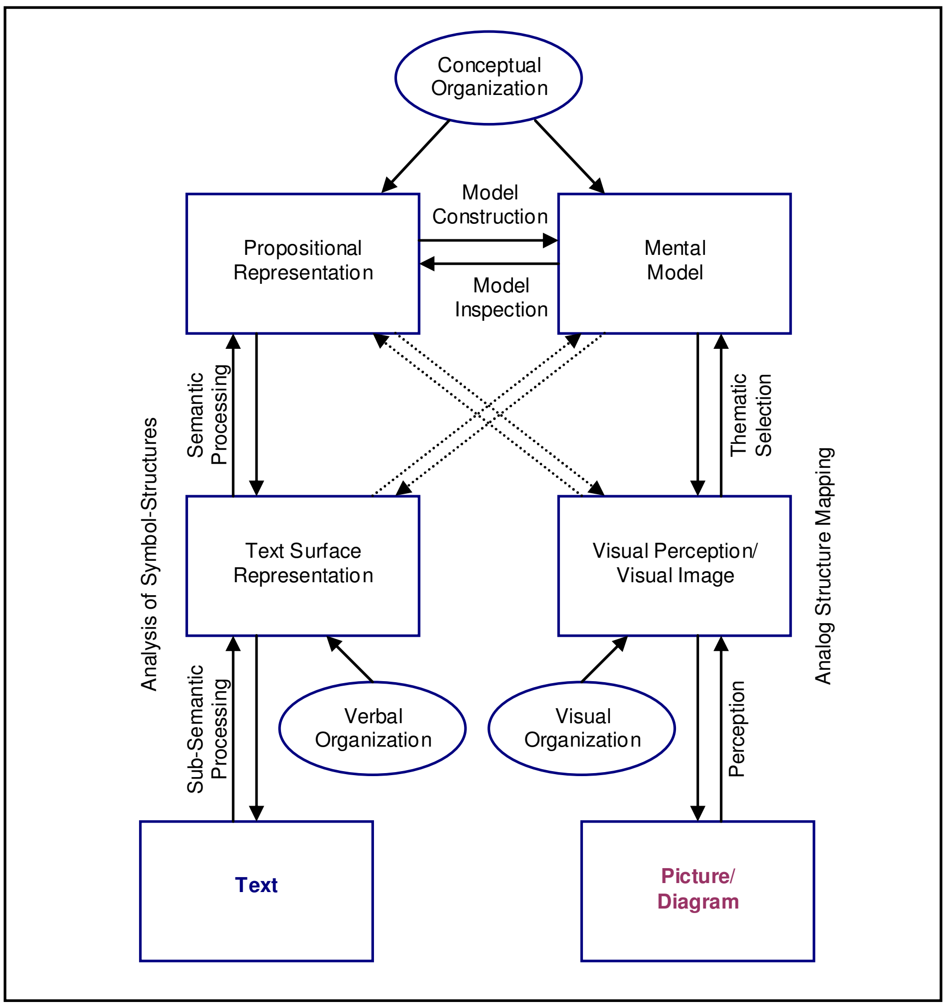


Figure 10. The IMMC (redrawn from Schnotz, 2002, p.109).

These three cognitive theories of learning from visual representations—DCT, CTML, and IMMC—are compatible with constructivist theory. Each theory (a) emphasizes the construction of meaning from a combination of visual and verbal information and (b) acknowledges the role of prior knowledge in the selection and organization of information that is taken from those multiple representations. However, these theories emphasize the construction of meaning *from* visual representations rather than the construction of visual representations themselves. In addition, the metacognitive aspects of learning from representations are not explicitly addressed in these three cognitive theories. While there is a need to more clearly describe the cognitive aspect of learning from visual elements, the cognitive processes involved in creating visual representations are even less well described. There is a need for a more comprehensive theory or framework that would have explanatory power in learning *with* and learning *from* representations. The theoretical and pedagogical components of a proposed exploratory framework, including semiotics, SFL, cognition, and metacognition, are presented Chapter 3.

The complex and diverse nature of the problem space within which the dissertation is situated has been suggested by the range of emerging and established constructs and theories described in the preceding sections. The problem space has been influenced by the results of research that has been conducted in a variety of fields, including science, science education, reading education, and cognitive science. As a consequence, the relevant literature contains terms that are used differently depending on the perspective of the authors (Gilbert et al., 2008). Table 4 contains an overview of some of the most common usages of the key terms found in the multiple representation, multimedia, and multimodal literature and of other terms used in this dissertation. When summarizing the results of related research in the following sections, I have attempted to provide consistency by using each term in a particular way, regardless of the terminology used in the original literature.

Table 4

Definition of Key Terms Used in the Dissertation[a]

Cognitive Theory of Multimedia Learning (CTML): A learning theory based on three underlying aspects: dual channels, limited capacity, and active processing (Mayer et al., 1996).
Diagram: A graphic format with the attributes of abstraction and spatial relationships (Winn, 1987). Diagrams convey or reveal information about processes or structures and may be considered as external models.
Dual Coding Theory (DCT): A cognitive learning theory that predicts two channels of mental representation, one for language and another for nonverbal objects (Paivio, 1991).
Exploratory framework: A collection of interrelated concepts that is more tentative than a model or a theory.
External representation: A representation that exists in a public format and is, therefore, available for viewing by others (Gilbert et al, 2008).
Image: The mental representation formed when individuals construct meaning from publicly available visualizations OR *a picture, illustration, or other publicly available external depiction*.
Inscription: Another term for external representation (Latour, 1988).
Integrative Model of Multimodal Comprehension (IMMC): Emphasizes mental representations of multimodal texts, with visual and verbal processing systems that are more complex than simply a second coding (Schnotz, 2002).
Internal representation: A mental representation constructed as individuals make meaning. External representations are public; internal representations may be called visualizations (Gilbert et al, 2008).
Metacognition: Thinking about one's thinking (Dickson, Collins, Simmons, & Kameenui, 1998). Metacognition includes aspects of knowledge, self-regulation, and motivation.
Metarepresentational competence: The full range of capabilities needed to work with representations, including selecting, producing, critiquing, modifying, and designing representations (diSessa & Sherin, 2000).
Model: Models facilitate construction and communication of scientific information and may serve as aids to memory and/or explanatory tools (Harrison & Treagust, 2000). Models represent the essential characteristics of objects or events and may include three-dimensional models, equations, diagrams, maps, and computer simulations (Gilbert, 2007). Models have explanatory power and are less tentative than frameworks but are more tentative than theories.
Multimedia: A combination of verbal and visual presentations. Verbal presentations include spoken and printed words; visual presentations include static and dynamic pictures (Mayer, 2001).
Multimodal: *A combination of presentation modes (e.g., verbal, gestural, visual)* (Jewitt, 2008) OR a combination of sensory modes (e.g., auditory, haptic, visual) (Mayer, 2005a).
Multiple representations: Two or more representations of the same information (van Someren, Boshuizen, de Jong, & Reimann, 1998); sometimes referred to as multiple external representations to distinguish between internal visualizations and public representations. Multiple representations need not be multimodal or multimedia.

Representation:
A symbol or sign that depicts other objects or events (Kozma & Russell, 2005a; Lynch, 2001). An experience with the representation affords knowledge of the object (Peirce, 1872/1986a, 1986b).

Representational Competence:
The set of skills and practices associated with the use of a variety of visual representations to think about, communicate, and conceptualize science (Kozma & Russell, 2005a).

Systemic Functional Linguistics (SFL):
A theory that views language as a semiotic tool used to negotiate, construct, organize, and represent experiences (Fang, 2005).

Text:
The diverse range of materials with which we interact and from which we construct meaning, including gestural, oral, visual, or written language and electronic media (Ministry of Education, 2006a) OR information in written or printed form.

Theory:
A scientifically accepted explanation of generalizations and principles that have been developed through extensive observations of natural phenomena (McComas, 1996). Theories integrate current canonical knowledge.

Visual literacy:
The ability to "discriminate and make sense of visual objects and images; create visuals; comprehend and appreciate the visuals created by others; and visualize objects in [the] mind's eye" (Bamford, 2003, p.1).

Visualization:
A representation in the public realm (i.e., external representation) OR a *representation constructed from publicly available symbols (i.e., internal representation)* (Gilbert et al, 2008).

Note. [a] If more than one definition is shown, the way in which the term is used in the dissertation is indicated by italics.

A Thematic Analysis of Recent Research on Diagram Use in Science

In this section, I present a thematic analysis (Boyatzis, 1998) of recent research that has examined diagram use in science. The analysis includes research focusing on multiple representation research, multimedia studies, and multimodal investigations. To prepare the analysis, I conducted an electronic search of 66 academic databases including Academic Search Premier, ERIC, JSTOR, and PsycARTICLES using a variety of phrases (e.g., *representation* AND *science*, *illustration* AND *science*). I manually searched the chapters of eight recent books on multimedia, multiple representations, and multimodal representations. With an additional parameter of publication dates between 2000 and 2010, I located articles and chapters reporting the results of 52 separate studies that examined the use of static diagrams in science. Each of these studies was published in a peer-reviewed book or journal and/or conducted by a well-known researcher. The purpose of this summary was to highlight research themes rather than to conduct a critical analysis of the research; therefore, each study was coded for up to three themes based on research focus and context rather than being critiqued. While this search was not exhaustive, it was a systematic attempt to develop a conceptual review of the existing literature (Greenhalgh, 1997; Stake, 2010); and the results of the coding process, shown in Table 5, are likely to be indicative of the themes appearing in the literature as a whole. All 52 studies, categorized and cross-referenced by theme, are presented in Appendix A.

Table 5

Common Themes in Studies of Diagrams in Science

Theme	Studies	
	n	%*
Learner-generated visual representations	17	32.7
Learning from visual representations	12	23.1
Student agency	10	19.2
Classroom-based	9	17.3
Assessment opportunities	8	15.4
Representational competence	7	13.5
Static versus dynamic representations	6	11.5
Cognitive Load	5	9.6
Strategies for learning from visual representations	5	9.6
Prior knowledge	3	5.8
Multimedia principles	3	5.8
Visual spatial ability	3	5.8
Internal versus external representations	3	5.8
Eye-tracking	3	5.8
Memory	2	3.8

*Each study was coded for as many as three themes.

The studies examining the seven most common themes that emerged from the systematic review are presented in the following sections. Each theme was identified as a focus in more than 10% of the studies that were located for the review; for each theme, the results are summarized and organized by the age of the participants unless otherwise noted.

Recent Research Theme 1: Learner-generated representations

One of the most common themes in recent research exploring diagram use in science is learner-generated representations, revealing a shift in emphasis from learning *from* representations to learning *with* representations. Studies have examined learners in kindergarten through university and have focused on aspects of representation, including student agency, assessment opportunities, and learning affects.

Acher and Arcà (2010) found that after instruction involving multimodal activities children aged three and up were able to imagine ‘looking inside’ items and then create representations that demonstrated an understanding of the properties of matter. Best, Dockrell, and Braisby (2010) found that four- to ten-year-olds’ representations of eclipses were an accurate indicator of depth of lexical and conceptual understanding. Pappas and Varelas (2009) observed primary students creating multimedia texts and using appropriate scientific modes to communicate their understanding through words and images. Students’ illustrations, which were often labelled diagrams, were central to demonstrating knowledge. However, Ehrlén (2009) argued that drawings by children aged six to nine did not adequately represent their conceptions of the Earth because she found that interviews revealed a number of alternative conceptions that were not evident in the students’ drawings.

Prain and Waldrip (2006) investigated Grades 4 to 6 students’ use of multiple representational modes and found that, while some students could translate between modes, other students needed more support in constructing and interpreting a variety of representations. The authors believe that some of the success in translating could be attributed to a stronger understanding of the conventions and functions of representations. In two related studies (Tytler, Peterson, & Prain, 2006; Tytler, Prain, & Peterson, 2007), Grade 5 students were observed to use a range of modes to represent evaporation. The teacher-mediated process of negotiating representations led to a better conceptual understanding for students and provided the teacher with more assessment opportunities.

Van Meter (2001) found that Grades 5 and 6 students were able to use drawing as an effective strategy for learning but only when prompting questions and comparison illustrations were used to scaffold the process. In a follow-up study, Van Meter, Aleksic, Schwartz, and Garner (2006) found that scaffolding the drawing process for Grades 4 and

6 students was a factor in successful learning from written information about birds' wings.

Jewitt, Kress, Ogborn, and Tsatsarelis (2001) analyzed multimedia texts created by Grade 7 students who were looking at onion cells under a microscope. They noted variations in both the written work and the drawings and suggested that these differences might reflect students' interests as well as the ways in which students were able to transform and work within the structures that the teacher introduced (e.g., scientific ways of drawing and reporting). Reiss, Boulter, and Tunnicliffe (2007) examined 13- and 14-year olds' representations of objects from the natural environment and argued that the drawings revealed a range of views about the natural environment. Waldrip, Prain, and Carolan (2010) observed Grade 8 students designing representations during multimodal units on force and matter. The authors noted that teachers mediated students' group negotiations about how best to represent concepts and used the student representations to assess conceptual understanding. In addition, tasks that involved the re-representation or transformation of concepts and ideas from one mode to another—the process that Siegel (1995) called transmediation—appeared to result in strong learning gains for students.

Botzer and Reiner (2007) worked with Grade 9 students learning about magnetic fields and found that progressive changes in learner-generated representations paralleled growth of conceptual understanding and of representational competence. Mortimer and Buty (2010) found that when Grade 11 students worked together to create representations about optics those students shifted between modes with a resulting transformation of knowledge, which led to a negotiated understanding of concepts.

Adadan, Irving, and Trundle (2009) compared high school chemistry students' understanding of matter before and after instruction that centered on multiple representations including diagrams. Although diagrams were not a specific focus, instruction based on multiple representations appeared to be more effective than traditional lecture-based approach. Ainsworth, Galpin, and Musgrove (2007) investigated university students constructing diagrams after reading about the cardiovascular system; they found that spatial abilities appeared to have no effect on learning or on the accuracy of diagrams and that the audience for the diagrams affected the clarity of the diagram but not the learning that occurred.

The studies summarized in this section were concerned with learner-generated representations, which is an emerging research focus that indicates a growing interest in learning *with* rather than *from* visual representations. Each study revealed insights into representational competence, learning possibilities, and instructional implications that could not have emerged from research focusing on learners making meaning from prepared texts. The results of these studies have implications for the theoretical aspects of future research. Cognitive theories of learning *from* prepared representations do not seem to adequately explain what happens when students create their own diagrams as they learn *with* representations. Additionally, the contradictory or disparate results in this group of studies suggest that learning with representations is a complex field of study that requires a unifying framework or theoretical approach to more fully understand the intricacies of what happens when students are creating their own representations.

Recent Research Theme 2: Learning from visual representations

Learning *from* prepared visual representations has been a focus of research since Malter (1947a, 1947b, 1948a, 1948b) reported the results of what he called a diagrammatic reading battery in which he assessed students' ability to read process diagrams, cross-sections, and conventionalized diagrammatic symbols such as lines, arrows, and dashed lines. Although there is a growing body of work examining learner-generated representations, learning from visual representations continues to be a common theme in explorations of diagram use in science as indicated by the results of the literature review. In this section, I summarize recent studies that have examined learners making interpretations from prepared diagrams.

Jewitt et al. (2001) found that when Grade 7 students were learning from visual representations the form of representation dramatically affected the construction of knowledge. Variables included the use of images and writing, use of color, two-dimensional (2D) or 3D representations, and animated or static presentation. Each form made different demands on the learner while providing different potential for learning. The choice of mode was seen as "central to the epistemological shaping of knowledge and ideological design" (Jewitt, 2008, p. 256).

Pintó and Ametller (2002) summarized an international series of studies investigating challenges faced by high school students when reading multimedia science documents

(Ametller & Pintó, 2002; Colin, Chauvet, & Viennot, 2002; Stylianidou, Ormerod, & Ogburn, 2002). In general, students from France, Italy, Spain, and the United Kingdom tended to interpret diagrams as narratives rather than as informational representations. Students had to be told to read captions; and once captions were read, students tended to change their interpretations of the related diagrams. When integrating multiple representations, students tended to use the more realistic modes (e.g., photographs and drawings) as a guide for interpreting more abstract modes (e.g., graphs and formulae). The varied uses of arrows (e.g., to connect labels or to indicate motion), missing or inaccurately highlighted elements of representations, and the use of new and unexplained symbols or icons posed a challenge for readers. Pintó and Ametller argued for explicit teaching of diagram conventions, noting that "an image is worth more than a thousand words only if the reader knows the codes to interpret and to design images" (p. 341). Harskamp, Mayer, and Suhre (2007) examined Dutch high school students' learning from multimedia and found that students learned better when diagrams were accompanied by aurally narrated text rather than written text; these results supported the multimodality principle, which states that "presenting some information in visual mode and other information in auditory mode can expand effective working memory capacity" (Low & Sweller, 2005, p. 147).

Butcher (2006) investigated the effects of university students viewing simplified or more detailed diagrams in addition to reading text passages about the heart. She found that the simplified diagram group got higher scores than the detailed diagram group on a post-assessment of domain knowledge and that both diagram groups got higher scores than the text-only group. In a related study, Butcher found that self-explanations[3] made when students viewed diagrams contained a higher number of correct inferential statements than self-explanations made when students simply read a written text.

McCrudden, Schraw, Lehman, and Poliquin (2007) compared the effects of undergraduate students reading a text passage and then studying a related flow diagram or rereading the text. They found that studying the diagram resulted in better recall of the steps in the sequence but there were no differences in recall of main ideas, indicating that

[3] Self-explaining refers to a type of verbal protocol in which participants explain the content of a text during learning. The goal is for students to actively make sense of what they are reading.

the adjunct flow diagram facilitated learning of procedures but not main ideas. In a follow-up study, McCrudden, Schraw, and Lehman (2007) compared the effects of reading a text passage and then studying a related flow diagram, studying a related list, or rereading the text. They found that university students who studied either the diagram or the list did better on subsequent tests of content than those students who reread the text. The authors suggested that both the list and the flow diagram made causal relationships explicit and highlighted key information from the text.

Schnotz and Bannert (2003) worked with university students to examine the effects of type of presentation (carpet diagram, circle diagram, text only) and the type of task (calculating time differences, circumnavigating tasks) and found that the text-only group was the most accurate when calculating time differences, followed by the diagram group, and the circle diagram group was the least accurate. (See Appendix B for examples of carpet and circle diagrams.) For circumnavigation tasks, the circle diagram group did the best, followed by the text only group, and then the diagram group. The authors argued that these results did not support Paivio's (1991) DCT and proposed an integrated model of learning from text and pictures.

Ainsworth and Loizou (2003) investigated the effect of asking participants aged 19 to 23 to self-explain as they learned about the human circulatory system either from written information or a series of labelled diagrams. Participants who received diagrammatic information learned more than participants who received written information, and the diagram recipients seemed to benefit more from self-explanations.

The results of these recent studies exploring the instructional effects of diagrams appear inconclusive; in some studies, reading diagrams was effective while in other studies, reading diagrams was challenging. This contradiction likely reflects the nature of the particular diagrams used in each study. For example, specific aspects of diagrams can either facilitate or hinder learning (e.g., Pintó & Ametller, 2002; Schnotz & Bannert, 2003). Additionally, inconclusive results might be explained by the specific research questions in particular studies. For example, McCrudden, Schraw, Lehman, and Poliquin (2007) found that reading diagrams supported learning about sequences although not learning main ideas. Researchers examining the learning of main ideas might conclude that the use of diagrams was ineffective. Taken together, however, this group of studies highlights the influence of context, task, and form and function of the representation on the learning potential of the diagram and supports the suggestion that cognitive theories of learning from multimedia or multimodal science texts do not sufficiently explain learning with visual representations.

Recent Research Theme 3: Student agency

Agency is a construct in social cognitive theory that considers individuals as agents who act to select, craft, and transform aspects of their environment and to shape events (Bandura, 2000). Agency can be personal, proxy, or collective. Personal agency refers to individuals being in control of their environments as a result of having responsibility for all choices. Agency by proxy refers to circumstances in which individuals rely on other people who have particular expertise to bring about the desired results. Collective agency refers to people’s shared efforts to produce results. A common theme in recent studies of learning with representations was student agency, where students worked together to select and shape the conventions that would be used in their representations. The participants in the studies ranged from Grade 1 to high school students; but in each case, studies were classroom-based and students made choices about how best to represent concepts, rather than simply redrawing a prescribed diagram.

As previously mentioned, Acher and Arcà (2010) found that after instruction involving multimodal activities young children aged three and up were able to create representations that demonstrated an understanding of the properties of matter. The children were encouraged to select a variety of representational modes and to create their own representations, thus given opportunities for agency. Brooks (2009) described Grade 1 students’ use of visual representations when learning about light and concluded that the process of drawing engaged students and focused their attention on key aspects of the concept. She proposed that drawing helped children to formulate their thoughts because the representations acted as a bridge between concrete and abstract thinking and moved them to higher levels of thinking while allowing interaction with the concept at inter- and intrapersonal levels. Student agency was also a factor in students’ learning by drawing because students had control over what to represent and how to represent it, allowing them to explore aspects of interest to them.

Prain and Waldrip (2006) investigated Grades 4 to 6 students working with multiple representational modes and suggested that, although student agency was important and that students should have opportunities to create their own representations, teachers needed to provide explicit instruction about the conventions and functions of representations. In two related studies (Tytler et al., 2006, 2007), Grade 5 students were observed to use a range of modes to represent evaporation. In these studies, student agency was viewed as an important aspect of developing conceptual understanding; but the teacher-mediated process of negotiating representational conventions was also critical.

In a descriptive study that examined three Grade 7 teachers' approaches to using representations, students were encouraged to create their own representations rather than merely learn a concept or a standard representation of a concept; the accompanying negotiation process seemed to foster student engagement (Hubber, Tytler, & Haslam, 2010). Waldrip et al. (2010) observed Grade 8 students designing representations during multimodal units on force and matter. Student negotiation about how best to represent concepts was an example of collective agency because students were given the opportunities to make choices and to shape the resulting standards of representation in the classroom.

Reiss et al. (2007) examined 13- and 14-year olds' representations of objects from the natural environment and argued that the drawings revealed a plurality of views about the natural environment that all had merit, even if not scientifically accurate in a traditional sense. For example, portraying the objects in a hierarchical relationship could be said to convey greater conceptual understanding than depicting objects in isolation. However, students who drew isolated objects still included details that indicated a familiarity with the critical aspects of the object, such as a bushy tail for a squirrel.

The researchers whose work is summarized in this section appear to share several common concerns about the use of diagrams in science education. While it is important that students learn representational conventions, it is even more important that students have opportunities to consider how and why those conventions came to be. The studies indicated that fostering student agency throughout the process of constructing representations tended to result in thoughtful consideration of the use of diagrams and other explanatory drawings. That consideration, in turn, likely facilitated the development of representational competence.

Recent Research Theme 4: Classroom-based research

Much of the early research in the use of visual representations in science was conducted outside of school settings in controlled laboratory conditions. While the results of that research might be interesting and indicate fruitful avenues for further research, laboratory-based studies do not adequately reveal the possibilities and challenges involved when students work with representations in an authentic classroom situation. Fortunately, several recent research programs have been based in classrooms, providing a much-needed perspective to the visual representation literature.

Brooks (2009) concluded that the process of drawing engaged Grade 1 students and focused their attention on key aspects of the concept under consideration. She proposed that drawing helped children to formulate their thoughts and moved them to higher levels of thinking. In the classroom setting, children also had opportunities to socially construct understandings of the concepts under investigation, an opportunity that has not been provided in most representational research conducted in laboratory settings. Pappas and Varelas (2009) observed primary students creating multimodal books as a culminating activity in a forest unit and noted that the children were able to appropriate scientific modes to communicate their understanding through words and images. The classroom setting meant that an exploration of students' work over time could be conducted, providing results that were richer than those yielded by one-shot laboratory investigations.

When Grade 5 students used a range of modes to represent evaporation, the teacher-mediated process of negotiating representations led to a better conceptual understanding for students and provided the teacher with more assessment opportunities (Tytler et al., 2006, 2007). Prain and Waldrip (2006) investigated Grades 4 to 6 students' use of multiple representational modes and found that, while some students could translate between modes, other students needed more support in constructing and interpreting a variety of representations and, as a result, teachers needed to provide explicit instruction about the conventions and functions of representations. Working with three classes each of Grades 4 and 6 students, Van Meter et al. (2006) found that scaffolding the drawing process was a factor in successful learning from written information about birds' wings. In each of these studies, the interactions between students and between the teacher and students were key components in the development of representations and representational competence. These interactions are not usually a factor in studies taking place outside of the classroom.

A descriptive study by Hubber et al. (2010) that was situated in three Grade 7 classrooms examined teachers' approaches to the use of representations. The teachers reported that negotiations about how best to represent concepts resulted in high-quality discussions that engaged students who learned more as a result. This study is another example of the insights that can be afforded by research that takes place in authentic settings. Mortimer and Buty (2010) found that when Grade 11 students worked together to create representations about optics those students shifted between modes with a resulting transformation of knowledge, which led to a negotiated understanding of concepts.

This small but growing body of classroom-based research highlights the potential of a representational emphasis in science education. Rather than examining how individual participants derive meaning from visual representations, these studies explored group negotiations of representational conventions with attendant discussions that engaged and challenged students' thinking. These studies also indicated the critical role of the teacher in scaffolding students' representational efforts and in mediating meaningful discussions about the use of representations. Research in authentic settings is a critical factor in expanding knowledge about of learning with representations.

Recent Research Theme 5: Using visual representations in assessment

Another small but growing body of research highlights the potential of using visual representations for assessment of students' conceptual understanding in science. Assessment can be either formative and used to inform teaching and learning or summative and used to evaluate learning. Formative assessment is sometimes referred to as assessment for learning, and summative assessment is sometimes labelled assessment of learning (Ministry of Education, 2005). Students' representations, including diagrams, may be useful in assessment of and for learning.

Brooks (2009) found that Grade 1 students' use of visual representations made their thinking visible and that their drawings provided opportunities for assessment of understanding as they were reviewed by the teacher and the student. Acher and Arcà (2010) found that young children were able to create representations that demonstrated their understandings of the properties of matter. Pappas and Varelas (2009) noted that primary students' book illustrations, which were often labelled diagrams, were central to demonstrating knowledge, indicating that learner-generated images were a valuable tool for assessment. Best et al. (2010) found that four- to ten-year-olds' representations of eclipses were an accurate indicator of depth of lexical and conceptual understanding. However, Ehrlén (2009) found that drawings by children aged six to nine did not adequately represent their conceptions of the Earth, noting that follow-up interviews revealed a number of alternative conceptions that were not evident in the drawings.

Reiss et al. (2007) examined 13- and 14-year olds' representations of objects from the natural environment and argued that the drawings revealed a plurality of views about the natural environment that all had merit. In an earlier study, Reiss et al. (2002) suggested that features such as layout, color, and imagery be used to assess representations for more than traditional scientific accuracy. Adadan et al. (2009) compared high school chemistry students' understanding of matter before and after instruction then used learner-generated representations to assess that understanding. They found that instruction that centered on multiple representations (including diagrams) was more effective in promoting understanding of the particle nature of matter.

With one exception, these studies indicated that learner-generated representations can be used to assess student understanding of science concepts. Ehrlén (2009) cautioned against accepting representations at face value since the ways in which teachers interpret students' drawings may not match the ways in which students intended to communicate meaning. Taking this small body of studies as a whole, it appears that students' drawings and diagrams can provide a particular perspective on understanding of concepts but that other forms of assessment, such as interviews and traditional tests and quizzes, should also be used.

Recent Research Theme 6: Representational competence

The sixth set of studies to be summarized is studies in which students' representational competence was explored. Waldrip et al. (2010) observed Grade 8 students designing representations during multimodal units on force and matter. The challenges faced by students as they negotiated how best to represent concepts indicated the need for explicit, just-in-time instruction about conventions, a specific aspect of representational competence. Botzer and Reiner (2007) worked with Grade 9 students learning about magnetic fields and found that growth in representational competence was indicated by learner-generated representations in a progression from concrete to macroscopic to formal representation and that conceptual understanding was related to representational competence. Chandrasegaran, Treagust, and Mocerino (2008) investigated an instructional approach in which Grade 9 chemistry students were explicitly taught about the use of macroscopic, submicroscopic, and symbolic representations and found that, although these students still had some difficulty translating between levels of representations, when compared with other Grade 9 students they did display a higher level of representational competence. diSessa and Sherin (2000) described a cohesive set of studies investigating students' metarepresentational competence—what students know *about* representations—noting that students in Grades 8 through 11 have a rich generative understanding of representations, even if that understanding is sometimes intuitive and limited.

Chittleborough and Treagust (2008) explored university chemistry students' ability to explain diagrams of equipment setup and found that the connections between the macroscopic level (equipment and supplies), submicroscopic level (molecules), and the symbolic level (equations) were not well understood. The authors recommended explicit teaching that focused on the levels of representation and on metavisualization, the metacognitive aspect of representational competence. Kohl and Finkelstein (2005b), working with university physics students, found that mode of representation was often related to student performance. Although the authors also attempted to investigate students' self-assessment of representational competence, the questionnaire responses did not reveal any clear patterns. In a follow-up study, Kohl and Finkelstein (2005a) found that an increased use of representations during instruction seemed to result in students' increased representational skill; however, they noted that their data did not allow a similar inference to be made about improvements in metarepresentational skills.

These research results indicate that although students might possess an intuitive understanding of representations explicit instruction is still required in order for students to build representation and metarepresentational competence. Students may not be able to accurately gauge their own levels of competence, and teachers and instructors need to be able to assess students' abilities and provide appropriate scaffolding.

Recent Research Theme 7: Learning from static or animated representations

There is a widespread assumption that learning from animations is more effective than learning from static representations (Hidrio & Jamet, 2008). However, the research literature does not indicate an advantage for one form over the other. Several recent studies have attempted to identify factors that influence whether an animation or a static representation is more effective.

Rundgren and Tibell (2009) investigated how students in Grades 11 and 12 and university interpreted static and animated representations of cells. Students were shown a diagram of three types of molecular transport through cell membranes and asked to explain their interpretations of the diagram. Students were then asked to interpret an animation showing similar information. When viewing the static diagram, students were able to identify that molecular transportation was the concept being depicted; but they did not always differentiate between the three types of transport. The animation was sometimes interpreted in comparison with the static diagram, some students extrapolated between the 2D and 3D information, and many students still had difficulty identifying the types of transportation being shown. Problems in interpreting the animation were attributed to varying levels of prior knowledge, which might include domain knowledge and representational competence, and to flaws in the design of the animation.

Mayer, Hegarty, Mayer, and Campbell (2005) examined the differences between college students learning *from* static illustrations or narrated animations in a series of four experiments. They found that neither the retention nor transfer of ideas was significantly improved when learning from animations. In fact, in two cases, the retention of ideas was significantly improved when learning from static illustrations; and in two cases, the transfer of ideas was significantly improved when learning from static illustrations. The authors suggested that factors affecting learning from static and animated representations could include the level of learner control over pacing and order of presentations and the mode of presentation (e.g., paper or computer screen).

Hidrio and Jamet (2008) explored university students' learning from multimedia documents that consisted of narrated information about engines presented in four versions: with no other information, with a single static diagram, with a series of static diagrams, or with an animation. Results indicated that there was a significant difference in the number of ideas recalled between students who heard the narration only and students who heard the narration and viewed an animation. There was also a significant difference in inferential problem solving for those students who viewed the animation as compared to students in all other groups. These results suggested that an animation can enhance learning of narrated information when compared to learning from a narration alone. The authors suggested that the processing requirements of the task likely influenced the results and that the most effective format for representation would depend upon the process being represented and upon the integration of the representation and the information through, for example, the use of arrows, highlighting, or pauses in appropriate moments to allow listeners to view representations.

Lewalter (2003) worked with university students to explore the effects of learning *from* static diagrams and animated visuals compared to learning from written information only. There was a significant difference in factual knowledge when learning from static or animated diagrams, and there was a significant difference in problem solving when learning from animated diagrams. However, there was no significant difference between learning from static or animated diagrams. These results support the large body of literature that suggests that diagrams and other visual representations can facilitate learning of scientific information, but they do not indicate that dynamic representations are superior to static representations.

Wiebe and Annetta (2008) used eye-tracking to investigate the effect of an audio track on undergraduate science students' viewing of PowerPoint slides, depending upon the level of integration between verbal and visual information (i.e., whether the written information directly referred to the representation), the number of words on a slide, and the format of the representation. They found that an audio track seemed to pace the viewing of the slide show and that students spent more time viewing slide contents when those contents were narrated. When a representation was referred to in the written information, an animation attracted significantly more eye fixations than a static diagram.

The results of these studies indicate that learning from animations is not always more effective than learning from static illustrations. Static diagrams may be more effective in some circumstances while dynamic representations may be more effective in other contexts. Factors affecting the effectiveness of a representation include whether corresponding information is presented orally or in writing, learner control over pacing of the multimedia document, the design of the representation (e.g., use of colors and arrows), the complexity of the representation, and the spatial and dynamic aspects of the concept being represented.

Taken together, these seven sets of studies highlight the potential for the use of visual representations in learning about, thinking about, and communicating about science concepts. Representations such as diagrams and labelled drawings afford assessment opportunities and can aid students in thinking about concepts. However, the use of representations may also pose challenges; in the following sections, the benefits and challenges that might arise when students are learning with visual representations are outlined.

When the coding process that was used to identify common themes in recent research on diagram use in science is used on the verification study described in Chapters 5 and 6, the three research themes would be learner-generated visual representation, classroom-based research, and representational competence. These three themes are among the seven most common themes of current research examining diagrams in science, indicating that the verification study encompassed themes of widespread interest within the research community.

Benefits of Learning with Visual Representations

Learning with visual representations includes learning from those representations (i.e., interpreting representations generated by someone else) as well as constructing understanding during the process of creating representations and strengthening understanding by communicating with representations. In this section, I summarize some of the benefits afforded by learning about science concepts with visual representations such as diagrams.

Research suggests that multiple representations can foster student motivation, interest, and conceptual understanding (Treagust, 2007). Multimedia representations may be able to convey more information than either words or pictures alone (Eilam & Poyas, 2008). Multimedia representations may lead to increased retention of information and to increased transfer of information during subsequent problem-solving (Mayer, 2001). Learning is likely to be improved if corresponding words and pictures are located close together (spatial contiguity principle, Mayer, 2001) and if they are presented simultaneously rather than sequentially (temporal contiguity principle, Mayer, 2001).

Diagrams used in combination with print information can reduce cognitive load by presenting information in such a way that learners can use their cognitive resources more efficiently (Ainsworth & Loizou, 2003). It is likely that diagrams help learners to understand information by reducing possibilities for interpreting print information. For example, a diagram may depict spatial relationships that a print passage may not include (de Vries, Demetriadis, & Ainsworth, 2009). When information is presented in two modes, the processing of that information can be distributed between the two systems, maximizing memory resources (Ainsworth & Loizou, 2003; Mayer & Moreno, 2002).

When learners transform information from one mode to another or one media to another (e.g., when they generate a diagram from print information), they engage with the information and are, therefore, more likely to process that information at a deep level (Brooks, 2009). The transformational affordances of working with student-generated and student-interpreted drawings and diagrams are a key aspect of the enhanced learning that has been found when students learn science with a representational emphasis.

Although more research is needed to fully explore why multimedia presentations of science information can improve learning, Ainsworth (1999) suggested that multiple representations may have three functions that may facilitate learning: complementing, constraining, and constructing. The use of more than one representation can provide complementary information when a concept is too challenging, too complex, or too abstract to adequately present in a single representation (for example, Figure 4 in Chapter 1). Multiple representations can be used to constrain interpretations if one representation is familiar and the other contains new information or if representations can be compared for similarities and differences. Multiple representations can also be used to construct understanding because each representation can reveal slightly different aspects of the concept under consideration.

Challenges of Learning from Visual Representations

Multimedia presentations or multiple representations may hinder learning in some situations. Domain knowledge and prior experience appear to be factors in learning with visual representations. Readers with low background knowledge (novices) may learn better with a combination of words and pictures while readers with high levels of background knowledge (experts) may learn better from pictures with no supporting verbal information (Mayer, 2001). One possible reason for this difference is that the experts' domain knowledge may facilitate interpretation of visual representation and render verbal information redundant. Readers with low spatial ability may be less successful with visual information (Mayer, 2001). Although multimedia documents are flexible because readers can decide when to turn their attention to the visual representations and when to focus on written information, that flexibility can lead to the reader omitting important information (Habel & Acartürk, 2007).

The challenges of learning from diagrams were investigated in a series of international studies (Ametller & Pintó, 2002; Colin et al., 2002; Stylianidou et al., 2002). These studies revealed that students tended to interpret diagrams from a narrative stance rather than interpreting them as sources of conceptual information, which resulted in incorrect inferences. Arrows and other components of diagrams posed a challenge for readers when those components were used in different ways (e.g., show direction, indicate motion, signify relationships) as did the use of new and unexplained symbols or icons and missing or inaccurately highlighted elements of representations. Stylianidou et al. (2002) noted that both page and diagram layout posed challenges for high school students; these difficulties were likely related to the lack of a clearly defined reading path for the text. Ametller and Pintó (2002) found that if high school students were not told to read captions then the captions and the information that they contained were ignored.

Research has also suggested that different forms of representations may be more effective for particular learners or for particular tasks (e.g., Butcher, 2006; Schnotz &

Bannert, 2003). The factors that determine which form is most appropriate for a specific combination of learners and tasks have not yet been clearly identified. However, it is likely that the functional relationship between a representation and associated verbal information influences the effectiveness of the representation as a learning tool.

Overview: Learning *with* Visual Representations

More research is needed to delineate the circumstances in which learning from multimedia and multiple representations facilitates or hinders comprehension of information. What does appear clear from the research is that although scientists already know how to interpret representations students are simultaneously learning how representations function as well as the information contained in the representations (e.g., Waldrip & Prain, 2006). Students should be supported in the process of generating their own visual representations, negotiating conventions, and using those representations as tools for learning rather than as established items to be memorized (e.g., Hubber et al., 2010). The creation of representations should be accompanied by meaningful hands-on activities (e.g., Brooks, 2009; Hubber et al. 2010; Waldrip et al., 2010). To develop students' representational and metarepresentational competences, teachers should mediate discussions and evaluations of the use of representations (e.g., Waldrip et al., 2010).

Another finding that emerges from the literature review is the need for a comprehensive theoretical model that would have explanatory power when students are learning with visual representations such as diagrams. A great deal of research has provided insights into making sense of prepared multimedia science texts. Less is known about the learning that occurs when students generate their own representations or create multimedia texts in order to think about, construct knowledge, and communicate ideas. The results summarized in this literature review suggest that both interpreting and constructing representations can lead to better understanding of science concepts. However, the existing models of cognitive learning do not fully predict or explain the interactive and constructive aspects of learner-generated multimedia text, nor do they acknowledge the complexities that are inherent in classroom learning conditions as compared to learning in a controlled laboratory setting. To address the need for a theoretical model, I developed a comprehensive framework that includes cognitive learning theory as one of several dimensions. The exploratory framework incorporates themes emerging from the literature review; the dimensions of the framework and its development are described in detail in Chapter 3.

Chapter 3

Development of a Theoretical Framework for Students Learning with Visual Representations

In this chapter, I describe the development of an exploratory framework that could be the initial step in creating a model or theory that has explanatory power for students learning *with* rather than *from* visual representations. I present theoretical aspects of the four dimensions that I propose are likely to comprise the framework. The exploratory framework, if verified, might provide a common theoretical perspective when comparing future studies of visual representations in science.

Classroom-based research in the area of students learning *with* visual representations in science has to date consisted of a few preliminary studies and several unconnected theoretical frameworks. Although these early studies reveal some promising classroom practices for learning with multimodal and multimedia texts, the realities of constructivist science classrooms suggest that any theoretical framework needs to consider a holistic view of language as a combination of verbal, printed, symbolic, and visual modes. In addition, the unconnected theories taken on their own do not fully reflect the complex nature of contemporary science education. In order to make meaning from scientific texts, students must draw inferences from a variety of sign systems, which requires a high level of print and visual literacy. Students must also learn the conventions of the variety of representations that they will encounter in science textbooks, digital sources, and trade books, including symbols, diagrams, pictures, graphs, and animations (Fang, 2005; Lemke, 1998). In order to construct understanding and to communicate in science, students must be able to select or create appropriate representations. The need for a comprehensive theoretical framework for learning *with* visual representations, including diagrams, has recently been addressed in the science education literature, with two frameworks proposed in the past four years. Ainsworth (2006) proposed a multidimensional model [sic] for addressing aspects of learning with multiple representations, while Carolan, Prain, and Waldrip (2008) developed a framework of pedagogical principles.

The Design, Functions, Tasks (DeFT) conceptual framework includes several dimensions that are thought to be influential in determining whether a learner might benefit from multiple representations and was particularly intended to inform research in the design of effective software (Ainsworth, 2006). Design aspects include the number of representations, the way that information is apportioned to each representation, the modes of the representations, the sequence of presentation of the representations, and the relationship between representations. The functions dimension includes complementary, constraining, and constructing functions as described in Chapter 2. The tasks dimension emphasizes the cognitive aspects of transforming representations and includes characteristics of the representations such as the modality (e.g., auditory, visual, written words, diagrams), level of abstraction (e.g., symbolic or iconic), specificity (e.g., how much information is contained), and type (e.g., graph, table, written information, picture).

A second multidimensional framework, the Identify-Focus-Sequence-Ongoing Assessment (IF-SO) framework, was developed to inform classroom use of representations and was based on pedagogy (Carolan et al., 2008). According to this framework, teachers need to *identify* key concepts at the planning stage and then *focus* on the form and function of the representations, clarifying conventions as necessary. The *sequence* of activities needs to include opportunities for student agency as learners represent concepts and manipulate and refine representations. The sequence also needs to address students' interests. *Ongoing assessment* can be formative or summative and should involve opportunities for students to assess their own representations.

Both the DeFT and IF-SO frameworks are multidimensional and address a range of factors that might influence learning—an aspect that the DCT, CTML, and IMMC do not accommodate. However, DeFT emphasizes learning from a combination of representations rather than learning *with* representations, while IF-SO was specifically intended to guide pedagogy rather than to address both teaching and learning and, as a result, emphasizes the teacher rather than the learner. Neither of these frameworks fully predicts nor explains the interactive and constructive roles of learner-generated, multimedia science texts.

Dimensions of the Exploratory Framework

I recognized the lack of an appropriate framework to describe learner-constructed representations as a way of making sense of science concepts during the preliminary stages of my program of research; thus, the development of an encompassing framework became an important aspect of the dissertation. The question guiding the development of the exploratory framework was: *What are the key dimensions of an encompassing framework for learning with visual representations as indicated by a review of relevant literature, and how might those dimensions be related?*

The exploratory framework described in this chapter was developed around the dimension of cognitive theories of learning, was informed by the model of science literacy described in Chapter 1, and drew on existing research results, principles of learning, ontological and epistemological features of contemporary science, and classroom pedagogy as outlined in Chapter 2. My previous investigations of middle school students' use of visual representations, described in Chapter 4, also informed the development of the exploratory framework.

Three dimensions in addition to cognition emerged from these considerations: metacognition, semiotics, and SFL. These three dimensions were identified as critical in a process that involved numerous conversations with colleagues and several attempts to develop an appropriate metaphor and create a 2D model. Representational competence, which emerged as a theme in the research literature, needed to be addressed in the framework; and the dimensions of SFL (described in detail later in this chapter) and semiotics would take into account functions of representations as well as the socially mediated conventions of signs and representations, another theme emerging from the research literature. Metarepresentational competence, or metavisualization, was also identified in the visual representation literature as being an important aspect of learning with representations and the dimension of metacognition would encompass this aspect. These three dimensions, together with cognitive theories of learning, are predicted to interact to influence the construction and interpretation of visual representations in a classroom context.

Metacognition

While cognitive models might explain the processes that occur when one is interpreting a visual representation, the processes involved in creating those representations are different. It is likely that metacognitive aspects are involved; questions that one might ask oneself when creating a visual representation include: *Is this the best way to represent the concept? What will someone else think when they try to interpret this representation? Have I used conventions that might make the representation easier for others to interpret?*

The metacognitive aspect of learning with visual representations is noted in the literature (e.g., Yore & Hand, 2010). Gilbert (2008) wrote about metavisualization skills and noted four criteria for metavisual status: an understanding of the conventions of representation, an ability to translate between representations, the ability to construct representations in a variety of modes and dimensions, and an ability to use representations to solve problems. These criteria are similar to the upper levels of representational competence that were proposed by Kozma and Russell (2005b) and that were shown in Table 2 in Chapter 2.

diSessa (2004) proposed that higher level representational competence could be thought of as metarepresentational competence (MRC). MRC includes inventing or designing new representations, critiquing and comparing representations, judging the appropriateness of representations, understanding how representations work, explaining representations, and learning new representations quickly. Although diSessa noted that the *meta* in metarepresentational was not meant to imply metacognition, some of the aspects of MRC do resemble aspects of the reading metacognition scheme shown in Figure 11.

The metacognitive dimension of interpreting diagrams and other visual representations likely includes aspects similar to aspects of reading metacognition, such as metacognitive knowledge (i.e., declarative, procedural, and conditional knowledge), motivational beliefs, and self-regulation (i.e., planning, monitoring, and adjusting). The metacognitive knowledge and self-regulation dimensions of Dickson et al.’s (1998) reading metacognition scheme parallel the awareness and executive control dimensions of an earlier science reading metacognition model (Yore et al., 1998). Awareness

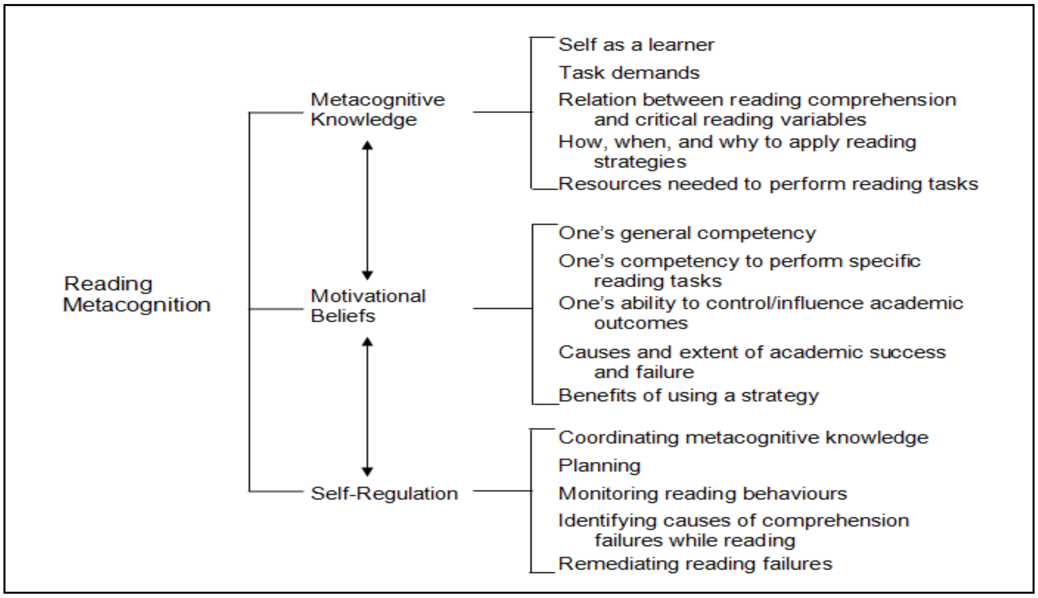


Figure 11. Aspects of reading metacognition (Dickson et al., 1998, p. 298).

involves declarative, procedural, and conditional knowledge and executive control involves setting purpose, planning, accessing prior knowledge (domain, topical, and discourse knowledge), monitoring progress, and adjusting strategies to improve progress. Dickson et al. also incorporated an affective domain that involves beliefs about motivation and self-efficacy. Building on the parallels between these two models, I adapted the reading metacognition scheme to create a representation metacognition scheme, shown in Figure 12, that includes the metacognitive aspects of metavisualization (Gilbert, 2008) and of MRC (diSessa & Sherin, 2000) that likely influence the creation or interpretation of diagrams and other visual representations.

Social Semiotics and a Visual Grammar

In addition to the dimensions of cognition and metacognition, the exploratory framework includes the dimensions of semiotics and SFL. Semiotics, in particular the area of social semiotics, has been credited with providing the theoretical foundations for working with visual representations (e.g., Carolan et al., 2008; de Vries & Lowe, 2010; Siegel, 1995). Social semiotics is based on the philosophy of Charles Sanders Peirce (Kress & van Leeuwen, 2006; Liszka, 1996) and deals with socially constructed meanings of signs. In Peirce's manuscripts on the nature of representations and the nature

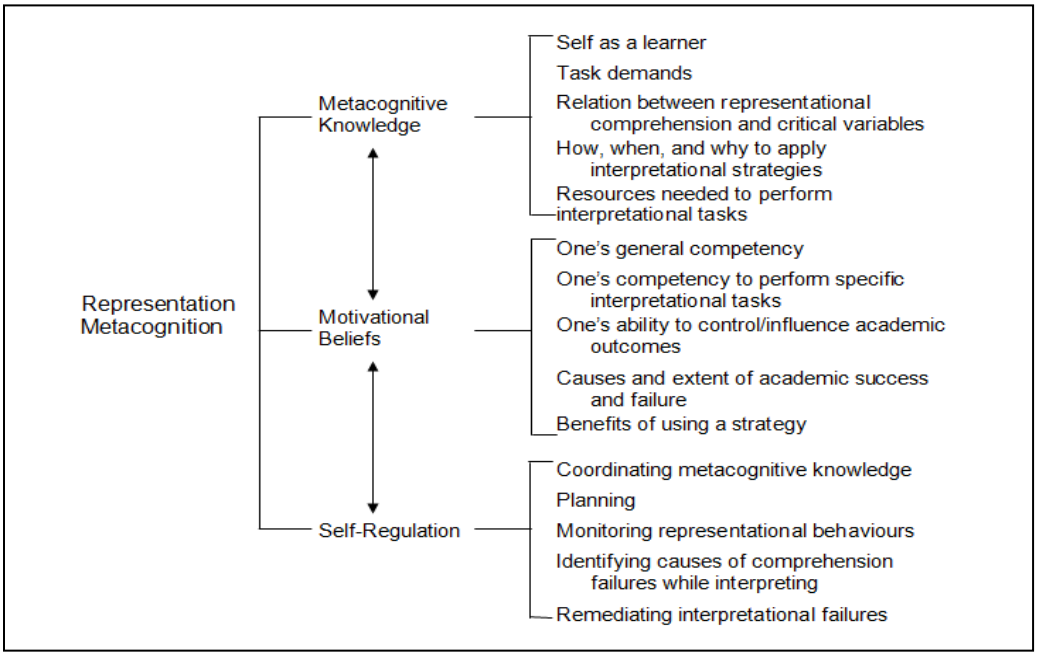


Figure 12. Metacognitive aspects of metarepresentational competence (adapted from a model of reading metacognition by Dickson et al., 1998).

of signs, he wrote, "a representation is an object which stands for another so that an experience of the former affords us a knowledge of the latter" (1873/1986a, p. 62) and "a sign is an object which stands for another to some mind" (1873/1986b, p. 66). Thus, Peirce (1872/1986a, 1872/1986b, 1955) proposed that a triadic relationship existed between signs, objects, and their interpreted meanings, as shown in Figure 13. This triadic relationship cannot be deconstructed into relationships between two aspects because the three components exist synchronously when a sign is interpreted; in fact, the existence of each component depends on the presence of the other two components (Liszka, 1996). Likewise, the triadic relationship is a snapshot of a single instance of interpretation since a particular sign can result in a different interpretant each time it is interpreted. The multiple interpretative possibilities inherent in Peirce's semiotic theory provide a connection with contemporary constructivist theory because the various interpretants that can arise from a particular sign are influenced by the viewer's prior knowledge and previous experiences. In addition, an object in one triadic relationship might serve as a sign in another triadic relationship—a characteristic of Peirce's theory that has been used to explain to the generative affordances of transmediation (Siegel, 1995). In fact, Siegel pointed out that the process of actively transforming text—a key aspect of constructivist learning—is consistent with Peirce's semiotic theory.

Peirce (1872/1986b) noted that a sign must have particular qualities or characteristics if it was to be considered a sign: material quality such as substance and shape, some connection with the object that it signifies, and someone to view the sign as a signifier, for "if it is not a sign to any mind it is not a sign at all" (p. 67). A sign requires that its producer and its reader share assumptions about the representation; therefore, the meaning of a sign is socially and culturally mediated. An example of the triadic relationship—in which the object is a labelled diagram of a dog, the sign is the word dog, and my interpretant is a visualization of my dog Ketza—is represented in Figure 14.

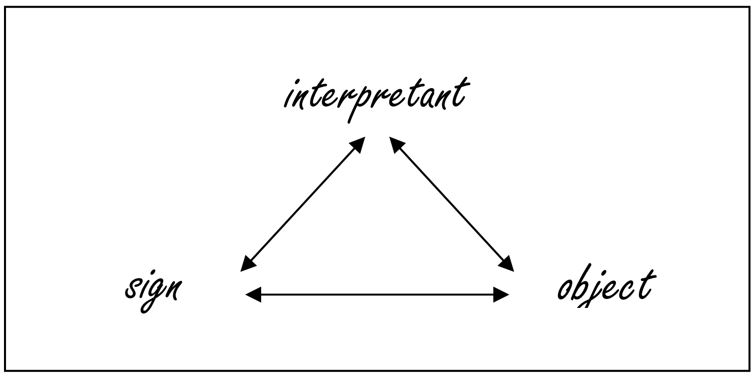


Figure 13. Peirce's triadic relationship (Liszka, 1996).

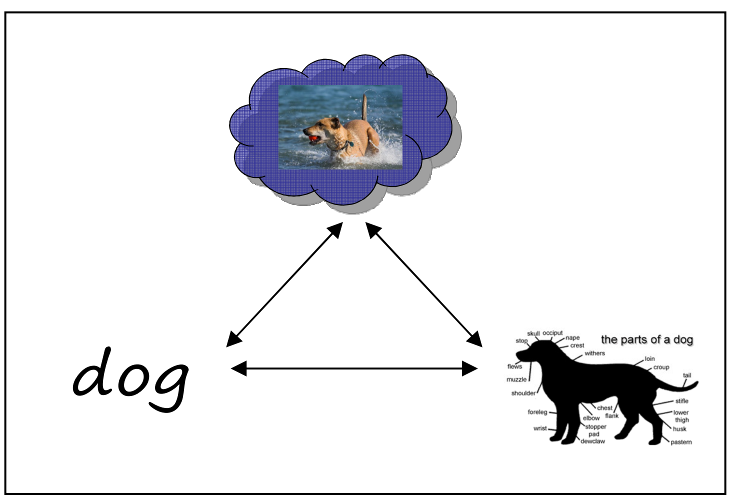


Figure 14. Example of Peirce's triadic relationship for the sign dog.

Peirce proposed a typology of signs based on the relationship between the sign and its referent object (Liszka, 1996). An *iconic* sign resembles some aspect of reality and shares similar characteristics with its object. A photograph is an iconic sign because it shows many of the features of the original object (Liszka, 1996). An *indexical* sign shows or exhibits the object rather than standing for the object. A weathervane is an indexical sign because it indicates the direction of the wind but does not resemble the wind (Liszka, 1996). A *symbolic* sign represents an object only because of convention or tradition and may share few of the features or characteristics of the object. The images that are typically used to denote public washrooms are symbolic because they convey meaning in a culturally and socially negotiated context (see Figure 15). An example of a symbolic image that I had difficulty interpreting, because I lacked the socially negotiated understanding, is also shown in Figure 15.

Figure 15. Iconic representations of symbolic signs. The photograph on the left was taken in Istanbul, but the meaning of the image is unmistakable. The photograph on the right was taken in Montreal but may not be easily interpreted as indicating the location of fire hose connections.

Using Peirce's typology of signs, a diagram showing the life cycle of a butterfly would be considered to be an iconic sign because some of the features of the object are shown in the sign. Diagrams may also be symbolic to some extent because of representational conventions that have been established. In the butterfly life cycle, arrows showing progression from one stage to another would be a symbolic aspect of the diagram.

Images, including representations such as diagrams, are distinguished from words by their properties of iconicism and/or indexicality. Icons are not common in written language and the connections between signifier (representation) and signified (what is represented) in language are often arbitrary because language is highly symbolic. Another difference between words and images is the lack of a formal convention for combining images into larger meanings the way words can be combined to create larger units of meaning, such as sentences or paragraphs. However, Kress and van Leeuwen (2006) developed a visual grammar that can provide a framework for understanding images—much like a story grammar provides a framework for understanding the elements of a narrative. This visual grammar was based on Halliday's work in the areas of social semiotics and SFL) and is built on a framework of ideational (representing), interpersonal (social relations), and textual (interactions of ideational and interpersonal) functions (Kress & van Leeuwen, 2006). According to visual grammar, representational structures or images can be narrative (portraying transitory relationships) or conceptual (portraying permanent relationships).

Conceptual images can further be categorized as classificatory, analytical, or symbolic (Kress & van Leeuwen, 2006), as shown in Figure 16. Classificatory images portray elements in subordinate or superordinate relationships and include taxonomies, tree diagrams, flowcharts, and networks. Analytical images portray elements in part–whole relationships that can be classified as unstructured (the whole is not shown or the parts are unlabelled), temporal (the parts are stages along an indicated timeline), exhaustive (the parts are shown joined together to make the whole) or inclusive (only some of the parts are shown on or in the whole), conjoined or compounded (parts are shown separately but connected by lines or placement, or parts are shown joined yet distinct), topographical (the parts accurately indicate physical and spatial relationships), topological (the parts may not be shown to scale or in actual spatial orientation), or dimensional and quantitative (the scale of the parts indicates quantity or frequency). Symbolic images portray profound meaning (e.g., artwork).

Instructional images in children's science information texts are usually diagrams (Unsworth, 2004), which are conceptual representations that are classificatory or analytical in nature. The verification study examined students' creation of representations

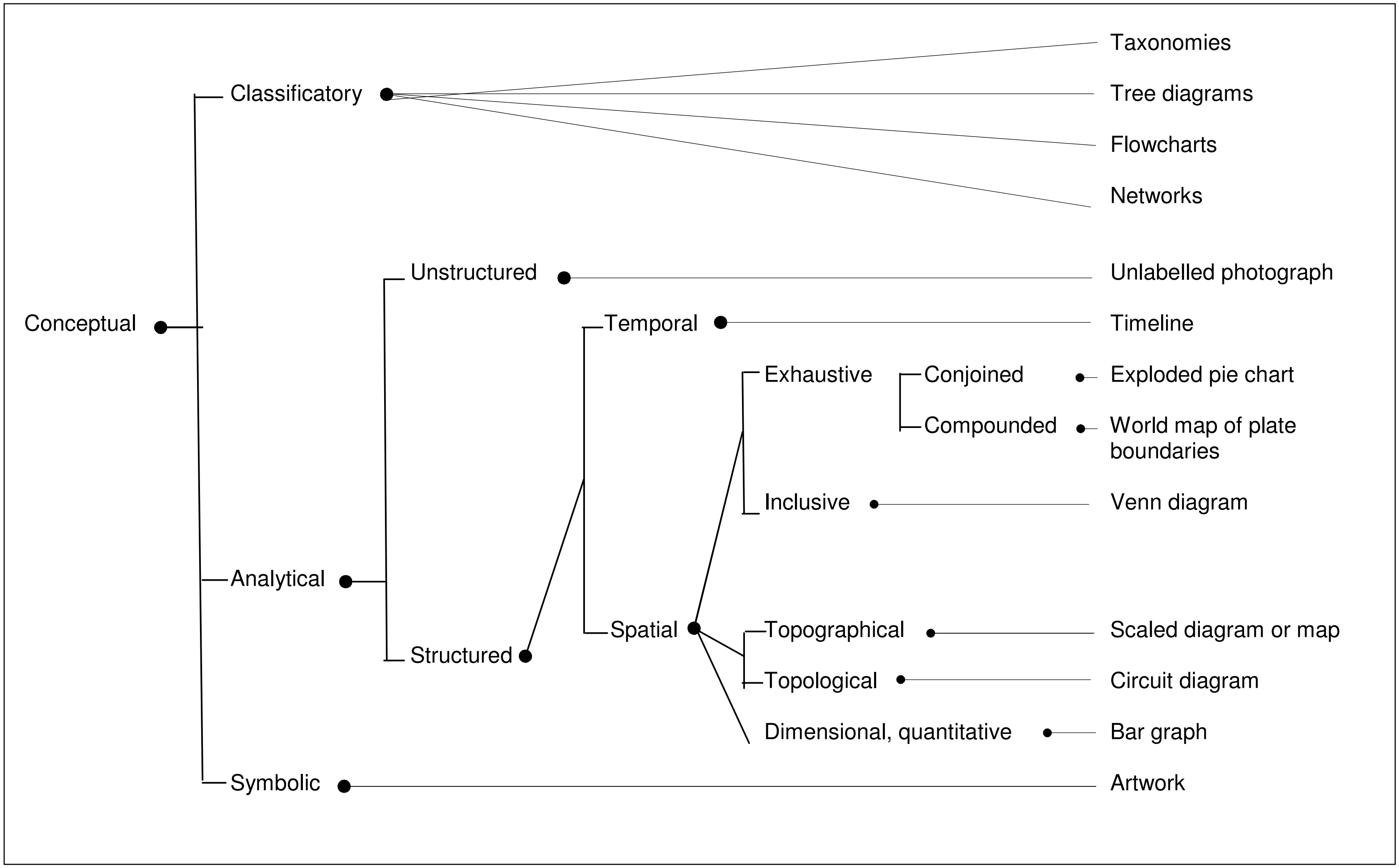


Figure 16. A taxonomy of categories and subcategories of conceptual representations (adapted from Kress & van Leeuwen, 2006) with examples from science.

about a science topic for which structured, spatial, analytical representations (diagrams and pie charts) would be most appropriate although no such constraints were imposed. Students would have been influenced, however, by their prior experiences with visual representations; and that prior experience would likely include reading textbooks with classificatory and analytical representations. The verification study research also investigated students' representational competence with structured, spatial, and analytical images (maps and diagrams).

Systemic Functional Linguistics and Functions of Representations

Language is a powerful communicative tool that is both necessary to and essential for science, not merely a sign system to be used in the acquisition and communication of scientific knowledge. Language is a resource for meaning, and SFL repositions language as a semiotic tool that is intricately involved in constructing, organizing, reconstruing, and negotiating experiences (Fang, 2005; Halliday & Martin, 1993). The language of science constructs, organizes, reconstrues, and negotiates science experiences and, as a result, has developed unique grammatical and textual features, such as high levels of lexical density (the amount of information contained in a text), abstraction, and technicality (the use of specialized terminology), and the frequent use of visual representations (Fang, 2005; Fang & Schleppegrell, 2010; Halliday & Martin, 1993; Unsworth, 2001).

From an SFL perspective, texts, including multimodal and multimedia science texts, can simultaneously convey three kinds of meanings: representational/ideational, interactive/interpersonal, and compositional/textual (Unsworth, 2001). The metafunctions of language are ideational, interpersonal, and textual meanings; the metafunctions of images are representational, interactive, and compositional meanings (Unsworth, 2001). *Representational/ideational* texts "construct the nature of events, the objects and participants involved, and the circumstances in which they occur" (Unsworth, 2001, p. 72). *Interactive/interpersonal* texts "construct the nature of relationships among speakers/listeners, writers/readers, and viewers and what is viewed" (Unsworth, 2001, p. 72). *Compositional/textual* texts" construct the value of information as a result of distribution, layout, and relative emphasis among components" (Unsworth, 2001, p. 72).

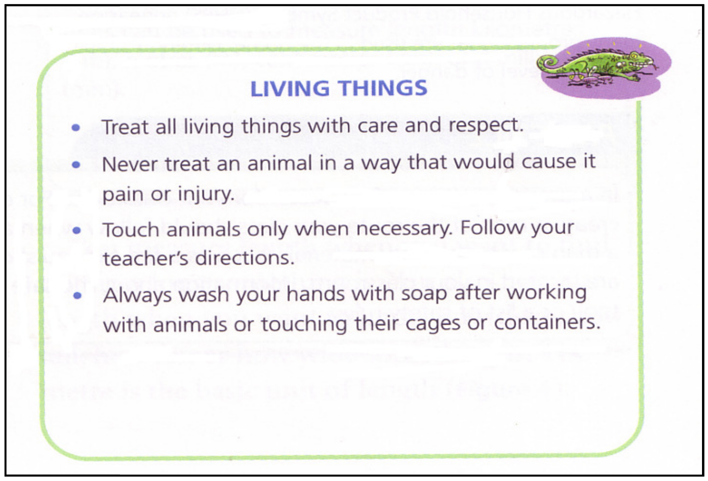
The shift in emphasis from written information to a combination of written and visual elements in conveying science concepts in science textbooks and trade books has been noted previously, both in this dissertation and in the related literature (e.g., Martins, 2002; Veel, 1998). Students must be familiar with the metafunctions of language and images in order to correctly interpret multimedia texts, and they draw on the metafunctions when constructing their own texts.

Functions of diagrams and other visual representations.

Multimedia texts contain verbal and visual information; for example, written information in science textbooks and informational trade books is typically accompanied by diagrams and other visual representations. When the verbal information refers to the visual representations, the texts are considered to be integrated (Wiebe & Annetta, 2008) or embedded (Gunel, Hand, & Gunduz, 2006; McDermott, Hand, & Cavagnetto, 2010). The functional relationship of the integration or embeddedness can be categorized as embellishment, reinforcement, elaboration, summarization, or comparison; the two most common usages have been identified as reinforcement and elaboration (Iding, 2000). In addition, visual representations such as diagrams can serve specific functions within a larger text. Several different functional categorization schemes appear in the literature, and two such schemes are presented here.

The first scheme, used by Iding (2000), is a conglomerate of other proposed schemes and considers the four functions of the diagram itself: identification, comparison, sequence, and combination. Iding notes that the most common type of diagram is the combination, which seems to limit the usefulness of this particular categorization scheme. The second scheme emphasizes the functions of the relationship between the diagram or other visual representation and the verbal (written or spoken) information (Carney & Levin, 2002).

Decorational pictures, such as the image in Figure 17, may mirror the theme of the verbal text but contain minimal information. Few, if any, meaningful links can be established between decorational representations and the verbal information with which they may be intended to correspond. Decorational pictures may not be integrated, or even referred to, in the written information. Decorational images created by learners do not afford an indication of learners' understanding of science concepts.


LIVING THINGS

- Treat all living things with care and respect.
- Never treat an animal in a way that would cause it pain or injury.
- Touch animals only when necessary. Follow your teacher's directions.
- Always wash your hands with soap after working with animals or touching their cages or containers.

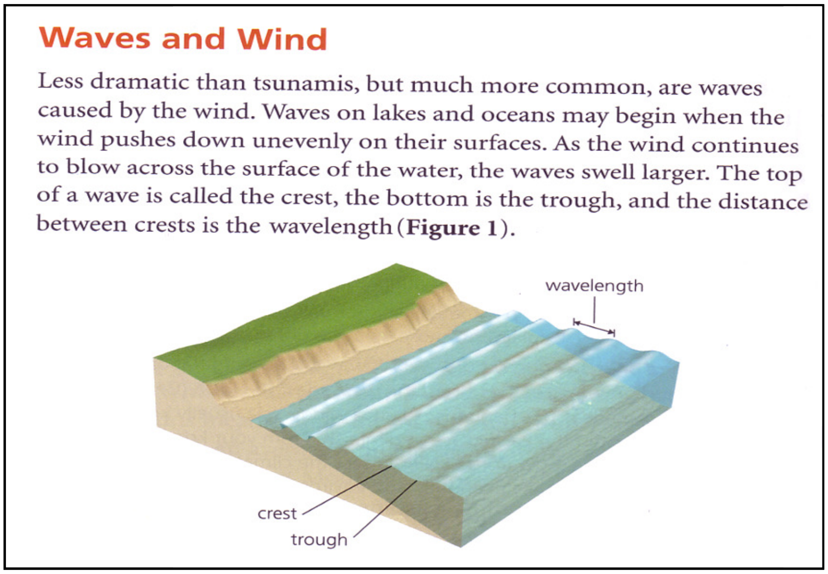
Figure 17. Decorational pictures bear little relationship to print information.[4]

Representational pictures, such as the image shown in Figure 18, mirror the information contained in writing. Representational images provide potential links to the written information with which they correspond; however, because the links are already established for the reader, those links may not lead to deep processing of information. Representational pictures are likely embedded in the corresponding written information with a signal, such as *see Figure 2*, indicating that correspondence to the reader/viewer. When learners create or select accurate representational images to accompany verbal text, those images are usually an indication that learners have some level of conceptual understanding.

Organizational pictures, such as the image shown in Figure 19, provide structures for organizing written information (e.g., illustrating steps in a sequence). Images that are organizational provide potential links to the written information with which they correspond; and since those links must be partially generated by the reader, they are likely to result in deeper processing of information than the links established by representational images. Organizational images should be integrated with verbal information for optimal interpretation of a multimedia text. When learners select or create organizational representations that accurately reflect verbal information and embed those representations, it is likely that those learners are demonstrating conceptual understanding.

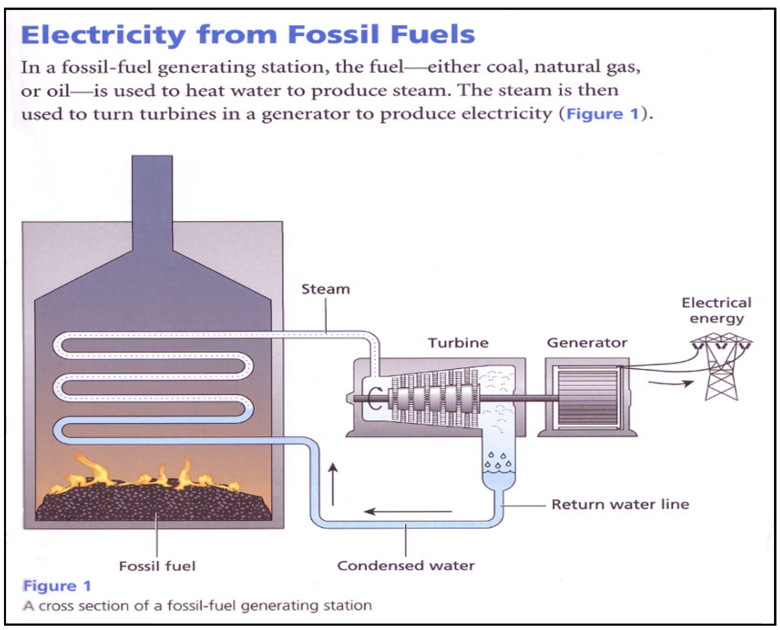
---

[4] From *Nelson B.C. Science 7 Student Text*, *1E,* by A. Chapman et al., 2005, Toronto, ON, Canada: Nelson Education Ltd. Copyright 2005 by Nelson Education. Reproduced by permission. www.cengage.com/permissions


Waves and Wind

Less dramatic than tsunamis, but much more common, are waves caused by the wind. Waves on lakes and oceans may begin when the wind pushes down unevenly on their surfaces. As the wind continues to blow across the surface of the water, the waves swell larger. The top of a wave is called the crest, the bottom is the trough, and the distance between crests is the wavelength (**Figure 1**).

Figure 18. Representational pictures mirror the information contained in print.[5]


Electricity from Fossil Fuels

In a fossil-fuel generating station, the fuel—either coal, natural gas, or oil—is used to heat water to produce steam. The steam is then used to turn turbines in a generator to produce electricity (**Figure 1**).

Figure 1
A cross section of a fossil-fuel generating station

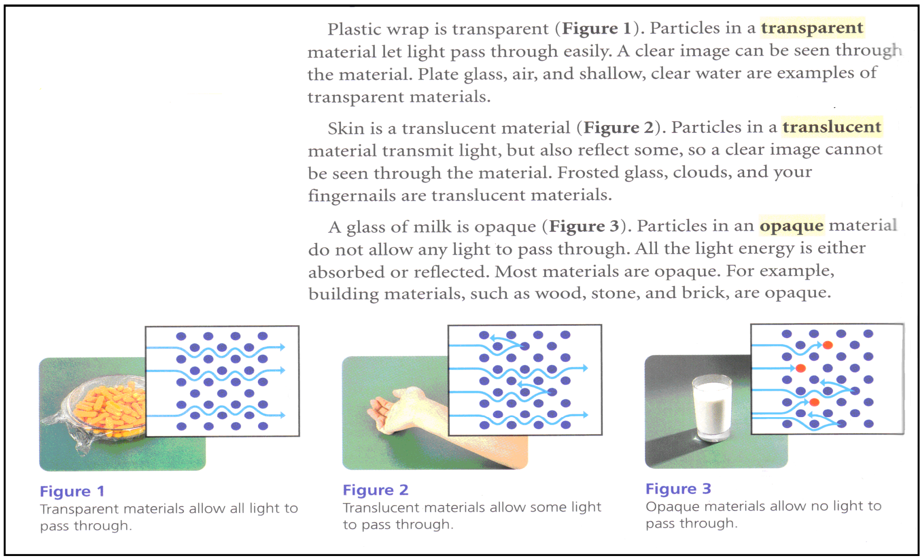
Figure 19. Organizational pictures provide structures for organizing information contained in print, illustrating steps in a sequence as in this example.[6]

---

[5] From *Nelson B.C. Science 7 Student Text*, *1E,* by A. Chapman et al., 2005, Toronto, ON, Canada: Nelson Education Ltd. Copyright 2005 by Nelson Education. Reproduced by permission. www.cengage.com/permissions

[6] From *Nelson B.C. Science Probe 6* by S. Doyle, J. Bowman, & D. Vissers, 2005, Toronto, ON, Canada: Nelson Education Ltd. Copyright 2005 by Nelson Education. Reproduced by permission. www.cengage.com/permissions

Interpretational pictures, such as the images shown in Figure 20, clarify challenging written information and contain additional information. Interpretational images provide opportunities for readers to create their own links between the written and pictorial information and are likely to result in deep processing of that information. Interpretational images must be integrated with the verbal information if the reader/viewer is to make sense of the multimedia text. When learners create or select accurate interpretational representations to accompany verbal text, those representations indicate a high level of conceptual understanding.


Plastic wrap is transparent (**Figure 1**). Particles in a **transparent** material let light pass through easily. A clear image can be seen through the material. Plate glass, air, and shallow, clear water are examples of transparent materials.

Skin is a translucent material (**Figure 2**). Particles in a **translucent** material transmit light, but also reflect some, so a clear image cannot be seen through the material. Frosted glass, clouds, and your fingernails are translucent materials.

A glass of milk is opaque (**Figure 3**). Particles in an **opaque** material do not allow any light to pass through. All the light energy is either absorbed or reflected. Most materials are opaque. For example, building materials, such as wood, stone, and brick, are opaque.

Figure 1
Transparent materials allow all light to pass through.

Figure 2
Translucent materials allow some light to pass through.

Figure 3
Opaque materials allow no light to pass through.

Figure 20. Interpretational pictures contain additional information to clarify challenging print.[7]

A fifth functional category, transformational pictures, includes images that are intended as mnemonic tools. Transformational pictures rarely appear in children's science text; however, the process of creating transformational images would develop strong links to the information and, thus, result in deep processing and memory of the information being represented (Carney & Levin, 2002). The highly personal nature of transformational representations means that those representations do not provide other people with opportunities for assessment of conceptual understanding.

---

[7] From *Nelson B.C. Science Probe 8 Student Text* by B. LeDrew et al., 2006, Toronto, ON, Canada: Nelson Education Ltd. Copyright 2005 by Nelson Education Ltd. Reproduced by permission. www.cengage.com/permissions

Research has indicated that readers who are aware of specific text structures, such as cause and effect or problem-solution, are better able to comprehend those texts (e.g., Armbruster, Anderson, & Ostertag, 1987; Cook & Mayer, 1988; McGee, 1982). Likewise, an awareness of the function of visual representations in science information texts may affect how students interpret those representations. When students are aware of the functions of visual representations, they may be able to select, use, or integrate visual elements with verbal information more effectively. Students may also be able to apply an understanding of functions during the creation of their own visual representations, whether those representations are meant to communicate information or to construct knowledge.

The four dimensions of cognition, metacognition, semiotics, and SFL are thought to influence learning *with* visual representations as well as learning *from* visual representations. In the following sections, I describe how these four dimensions might interact.

Relationships between the Dimensions of the Exploratory Framework

Once the likely dimensions of the framework were identified, the potential relationships between the dimensions were examined. Cognition and metacognition seemed to fit naturally together as two aspects of the thought processes involved in creating and interpreting visual representations. Cognition was categorized as a theoretical process while metacognition was conceptualized as something that could be explicitly taught in the classroom; students could learn metacognitive strategies, such as asking themselves questions about their understanding while reading a multimedia text (Dickson et al., 1998). When the other two dimensions of the exploratory framework were examined, this pairing also seemed appropriate for SFL and semiotics, with semiotics being the theoretical aspect and SFL the aspect that could be explicitly taught, in the form of conventions and functions of representations. Both social semiotics and SFL build on work by Halliday (e.g., Halliday & Martin, 1993), which also contributed to the decision that these two dimensions were closely related to one another.

An important stage in the development of the exploratory framework was building a 3D) physical representation (Tippett & Yore, 2009b). Initially, attempts were made to draw a 2D model, using analogies ranging from the solar system to a braided wire; but the drawings failed to fully capture the dimensions and their interactions. A 3D representation was designed using inexpensive materials that could be easily manipulated. The steps in creating the physical model are shown in Figure 21.

The cognitive (dark purple) and metacognitive (light purple) strands are entwined to form a single strand. The semiotics (dark blue) and SFL (light blue) strands are entwined to form a second strand. These two strands are then entwined with each other, creating a verbal channel in which all four components are connected and interacting but in which cognitive and metacognitive processes are closely related and semiotic and SFL are closely related. The process is repeated, with different colors to represent that the specific characteristics of each component may be different depending on mode, to create a visual channel. The clear plastic tube surrounding each channel could represent prior knowledge, which includes domain knowledge, topic knowledge, and discourse knowledge. Prior knowledge is likely to be an essential aspect of the framework; according to constructivist theories, the construction of new knowledge is dependent upon prior knowledge, and research indicates that prior knowledge and domain knowledge are indeed factors in learning from visual representations (e.g., Butcher, 2006; Cook, Carter, & Wiebe, 2008).

The visual and verbal channels are then connected with links that are thought to correspond to the functions of the visual representations, as described earlier in this chapter. Figure 22 shows the lack of links afforded by decorational representations. Any links that are constructed would likely be weak. Figure 23 shows the links that might be established when reading/viewing multimedia text with representational or organizational images embedded in written information. These links would be greater in number and stronger than the links available with decorational representations. Figure 24 shows the links that readers/viewers would have to construct when interpreting multimedia text containing interpretational representations. The number of links between the verbal and visual channels would likely be small, but those links would be very strong due to the conceptual processing required.

In Table 6, the four dimensions of the integrated exploratory framework are shown as they might be expanded into macro and micro levels to reflect the specific foci of this project. The macro level refers to the overarching classroom activity or goal while the

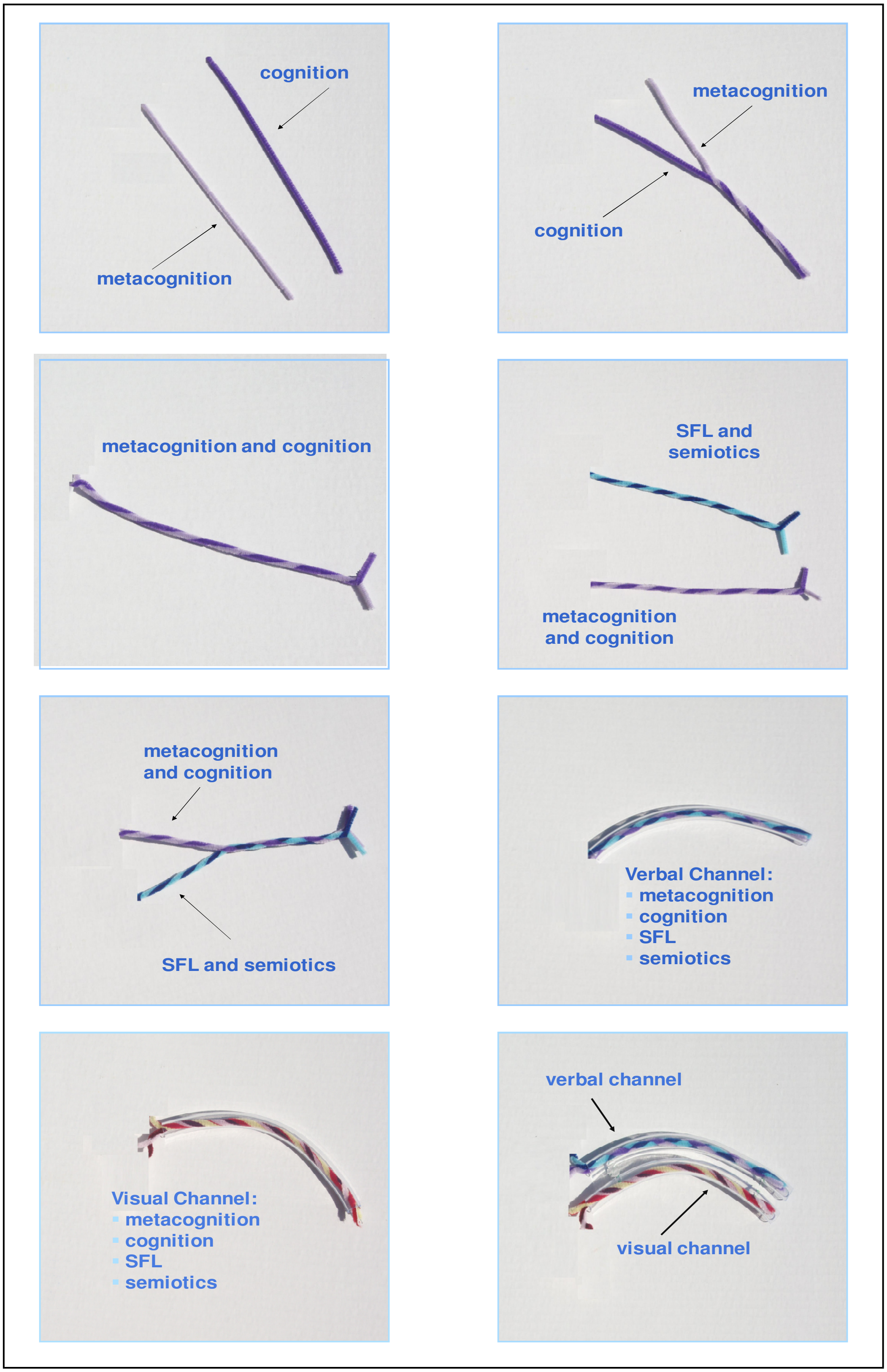


Figure 21. Steps in building a physical representation of the exploratory framework.

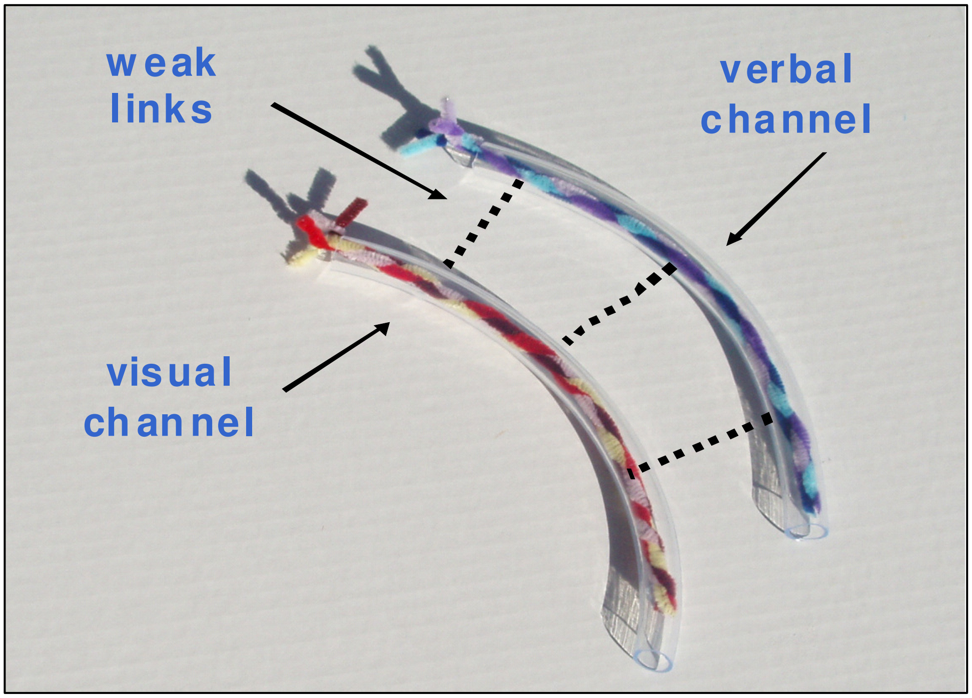


Figure 22. Decorational visual representations provide few, if any, opportunities for readers/viewers to create links; and those links would be weak.

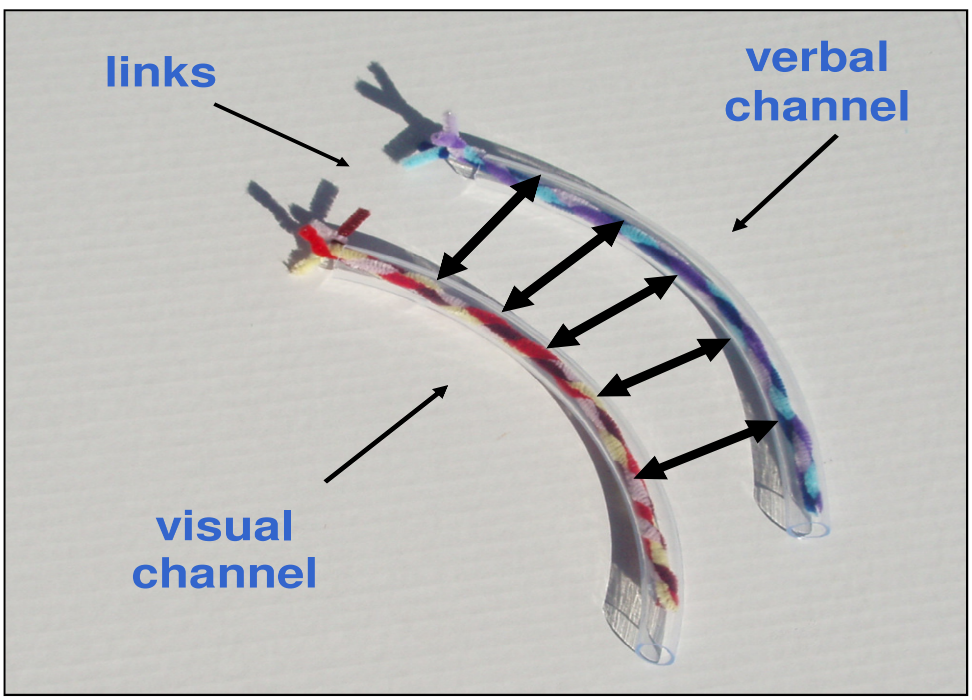


Figure 23. Representational or organizational visual representations would provide strong and intentional links with information in the verbal channel.

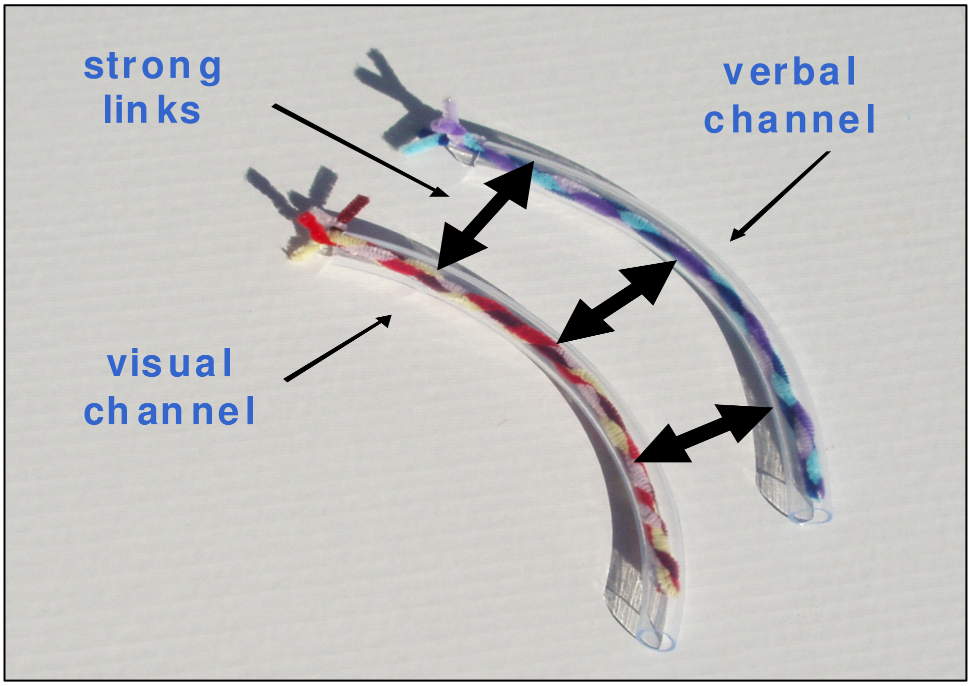


Figure 24. Interpretational visual representations require readers/viewers to create their own links, resulting in a smaller number of links, but those links would be very strong.

Table 6

Exploratory Framework Applied to the Verification Study

Classroom activity	Macro level (Science context)	Micro level (Study focus)
Language and Literacy Focus: Reading and Writing	Reading and Writing in Science	Interpreting and Creating Diagrams
	Theoretical Model	
Framework aspect	Macro level (Science context)	Micro level (Study focus)
Cognition (Baddeley or Wittrock)	Conceptual Growth and Change (Vosniadou)	Dual Coding Theory (Paivio) or Integrated Model (Schnotz) or Multimedia (Mayer)
Metacognition (Ford & Yore)	Reading Metacognition (Dickson, Collins, Simmons, & Kameenui)	Representational Metacognition or Metarepresentational Competence (diSessa & Sherin)
Semiotics (Peirce)	Visual Grammar (Kress & van Leeuwen)	Conventions of Scaled Diagrams (Kress & van Leeuwen)
Systemic Functional Linguistics (Halliday & Martin)	Functions of Scientific Language (Fang)	Functions of Representations (Carney & Levin)

micro level is the specific focus of that activity. In the case of the verification study, the classroom activity was reading and writing in science; the focus of that activity was creating diagrams based on a written passage containing unfamiliar science information. The dimension of cognition would be related to conceptual growth and change involving that new information and would be described by models of cognition such as DCT (Sadoski & Paivio, 2001), CTML (Mayer, 2005a), or IMMC (Schnotz, 2002). The dimension of metacognition would be related to reading metacognition (refer to Figure 11) on the macro level and representational competence (refer to Figure 12) on the micro level. In order to create accurate representations, students would need an understanding of conventions and be able to use procedural and declarative knowledge. The dimension of semiotics would be related to the visual grammar proposed by Kress and van Leeuwen (2006) on the macro level and to conventions of labelled diagrams because students would be applying their knowledge of conventions to create appropriate representations. The SFL dimension of the exploratory framework would be related to the functions of scientific language in general and to the functions of visual representations in particular; students would need to select the most appropriate form of representation for the science information they were trying to communicate.

Summary

The exploratory framework encompasses the components of visual thinking that were outlined by Trumbo (1999): metacognition, creative and critical thinking, cognition, and content knowledge. Aspects of metacognition include thinking about visual representations, the ability to think with visual representations, the evaluation of visual representations, and the ability to use visual representations as a substitute for real-world activities. Aspects of creative and critical thinking include recognizing and elaborating patterns, thinking intuitively, working with ideas flexibly and fluently, and thinking analytically. Aspects of cognition include the role of the eye and brain and the ability to interpret visual representations. Aspects of content or domain knowledge include scientific principles, symbols and notations, and conventions of representations.

The four dimensions of cognition, metacognition, semiotics, and SFL form an integrated framework that is expected to have explanatory qualities when applied to situations where students are interpreting and constructing visual representations. The multidimensional nature of the exploratory framework addresses a gap in the research literature on learning *with* visual representations. I have chosen to use the term framework rather than model or theory in order to reflect the tentative nature of the construct.

The framework is intended to encompass both dynamic and static visual representations although the dissertation focused on static representations. The exploratory framework could be used to guide future research examining learning from and with visual representations in science. The framework could also guide improvements in classroom pedagogy that might lead to improved visual literacy, better comprehension of science concepts, and enhanced science literacy.

In Chapter 4, I present a case-to-case synthesis of research that I previously conducted with the Pacific CRYSTAL project. The exploratory framework informed my analysis of four case studies; in turn, I considered the results of the synthesis in the further development of the framework. The exploratory framework also informed the design and implementation of the verification study that is described in Chapters 5 and 6.

Chapter 4
A Case-to-case Synthesis of Previous Research

A case-to-case synthesis is an analytical technique that can be used to reveal commonalities, develop more generalized knowledge, and build understanding across a broader problem space, which allows for greater generalizability of results (Yore & Rossman, 2010). In this chapter, I present overarching themes emerging from four case studies that I conducted as a part of the Pacific CRYSTAL *Explicit Literacy Instruction Embedded in Middle School Science* project that ran from 2005 to 2010. It should be noted that this case-to-case synthesis is limited by the fact that I held key roles in researching, writing about, and presenting each of the case studies, which means that the analytical lens of the case-to-case synthesis is similar, if not identical, to the lenses used with the original studies. However, the synthesis is informed by a comprehensive literature review and many hours of interactive reflections with participating teachers and co-researchers.

My personal interest throughout the project was centered on the use of visual representations, and that focus influenced the selection of activities for professional development. My interpretations of participants' actions and artefacts in each of the four case studies presented here were influenced by my curiosity about visual representations. As I synthesized the results of the case studies, I had the proposed exploratory framework (see Chapter 3; Tippett & Yore, 2009b) in mind as I sought evidence that would or support the need for changes to or strengthen the framework. However, my awareness of this analytic stance meant that I actively searched for other themes as I attempted to reduce possible bias in the metasynthesis.

Case-to-case syntheses may be case-oriented: a working theory is developed from an initial case and then the robustness of that theory is tested by its application to subsequent cases (Yore & Rossman, 2010). Case-to-case syntheses may be variable oriented: cases are analyzed simultaneously to reveal themes. These two approaches to the case-to-case synthesis may be blended, resulting in a mixed approach where the analysis is balanced between theory-testing and identification of variables. In this metasynthesis, I took a blended approach to the analysis of the four case studies.

A case study is an in-depth investigation of an individual, event, activity, or program where the case is bounded by time and place (Cresswell, 1998). Typically, case studies are situated within a physical, social, or historical setting that provides context for the case. A description of the *Explicit Literacy Instruction Embedded in Middle School Science* project provides the social and historical context for the four individual cases summarized and synthesized here, which include an investigation of students' use of informational brochures, an exploration of students' use of Foldables® and informational posters, a descriptive study of one teacher's implementation of a multimodal unit, and a reflection on the creation of an instructional resource. In the following sections, the four cases are summarized and then the results of a case-to-case synthesis are presented. The question guiding the metasynthesis was: *What common themes emerge from previous Pacific CRYSTAL case studies, and how might these themes relate to the exploratory framework?*

Context: An Overview of the Professional Development Project

The *Explicit Literacy Instruction Embedded in Middle School Science* project was initiated in the spring of 2005 at the request of a small group of teachers from two middle schools in a local school district that had English and French programs of instruction in Grades 6, 7, and 8. Preliminary collaborations amongst teachers, administrators, and researchers indicated that a community-based engineering research and development approach would be more appropriate than a typical scientific research inquiry approach. This approach (identify needs and opportunities, design solutions, evaluate solutions, and revise solutions) provided flexibility and enabled researchers to take advantage of case study opportunities throughout the project (Anthony, Tippett, & Yore, 2010). The overarching purpose of the project was to develop, field-test, refine, and eventually disseminate authentic activities that supported the development of literacy in the context of science instruction. Initial guiding questions for the project were: *What is the effectiveness of particular literacy strategies on students' literacy abilities, particularly reading and writing? What impact do particular activities have on students' understanding of science? What happens when teachers implement particular literacy activities in their science instruction?*

The National Science Education Standards (USNRC, 1996) emphasize inquiry teaching and learning, integration of pedagogical content knowledge, collaboration, and long-term professional development activities; they situate teachers participating in professional development as reflective practitioners, knowledge producers, leaders, and members of a community of practice. The *Explicit Literacy Instruction Embedded in Middle School Science Classrooms* project was designed to meet these standards with a series of workshops that were collaboratively planned and led by teachers and researchers. Teachers were introduced to new instructional approaches; because of the long-term design of the project, they had ongoing opportunities to implement the approaches then share and reflect on the results of the implementation (Tippett & Yore, 2010).

A working framework for the project, shown in Table 7, was adapted from the National Geographic Theme Sets (National Geographic School Publishing, 2008). These theme sets provided an example of opportunities for embedding explicit literacy activities into existing science programs. As the project progressed, oracy was added as the fifth dimension of the framework in order to reflect provincial and school goals as well as to emphasize the importance of discussion in constructing understanding of science concepts.

Table 7

Working Framework for Explicit Literacy Instruction, with Examples

Vocabulary/Concept development	Reading comprehension strategies	Visual literacy	Science reading and writing genres
Topic-specific concept words	Determining importance	Labelled diagram	Information brochure
Greek and Latin roots	Synthesizing	Labelled photograph	Explanation
Concept mapping	Visualizing	Cross-section	Cause-effect
	Making connections	Flow diagram	Problem-solution
	Questioning	Cut-away diagram	How-to book
	Inferring	Resource map	Feature article
		Photo montage	Encyclopaedia entry

Professional development in this five-year project was centered on a series of workshops during which the multimodal character of scientific discourse and the constructional and communicational roles of discourse in doing and learning science were emphasized. Teachers were introduced to a variety of discipline-specific literacy strategies that reflected the nature of science, and the research evidence behind each strategy was discussed. Opportunities to discuss the implementation of the strategies and to share ideas about embedding the strategies in the science curriculum were a regular part of each workshop. Professional development included demonstration lessons, team teaching, and finally, the collaborative creation of instructional resources. Participating teachers were generalists who were required to teach a number of other subjects in addition to science, rather than specialists who taught only science or who had university degrees in science.

Year 1 was devoted to providing a theoretical background for interested teachers, exploring aspects of science literacy and the role of language as a cognitive tool in science. In addition, participants developed a tentative agenda for the next year's workshops. In Year 2, participating teachers from both English and French streams began by identifying opportunities for embedding literacy strategies into the science curriculum, using two newly adopted textbooks series: *BC Science* (McGraw-Hill Ryerson, 2004, 2005, 2006) and *Science Probe* (Nelson, 2005a, 2005b, 2006). Subsequent workshops focused on specific strategies that emphasized the nature of the discipline of science: concept mapping, reading and creating labelled diagrams, and creating informational posters. Teachers from the third middle school in the district joined the project in Year 3, and the professional development activities focused on multimedia representations and included writing in science genres, using reading strategies such as THIEVES[8] (Manz, 2002), creating informational brochures, investigating the functions of visual representations (Carney & Levin, 2002), and developing rubrics for science assessment. During Year 4, participation was limited to lead teachers willing to consider becoming professional development facilitators in Year 5. The focus of the professional development activities shifted to include planning, with all previously introduced literacy activities being purposefully embedded in mandated science units. Workshops about Foldables® (3D graphic organizers that include both written and visual information, Zike,

---

[8] THIEVES is a prereading strategy that sets the purpose for reading using an easily remembered acronym. Students learn how to "steal" information from the **T**itle, **H**eadings, **I**ntroduction, **E**very first sentence, **V**isuals/Vocabulary, **E**nd-of-chapter questions, and **S**ummary before reading the entire text selection (Manz, 2002).

2001) and argumentation were also held during Year 4. The sequence and focus of the professional development workshops that were offered throughout the project are shown in Table 8. In the summer between Years 4 and 5, the lead teachers met to prepare an instructional resource that has since been shared with all content area middle school teachers in the district.

Table 8

Sequence and Focus of Professional Development Activities

	Focus	Activity	Intended outcomes
		Year 1 (2005–2006): Exploring the problem space	
Workshop 1	Information	The literacy component of science literacy	Generate interest in the project and recruit participants
Workshop 2	Information	Language as a cognitive tool	Develop understanding of theories of language and reading
Workshop 3	Information	Feedback on the process and workshops	Project planning and prepare of an agenda for Year 2
		Year 2 (2006–2007): Building a repertoire	
Workshop 4	Information	Project review	Establish procedures for quantitative data collection Set goals for upcoming workshops
Workshop 5	Information	Identify literacy foci in textbooks	Generate a list of science literacy strategies to be explored in upcoming workshops
Workshop 6	Vocabulary/ Concepts	Concept mapping	Use concept maps to assess pre- and post-unit understanding of science concepts
Workshop 7	Information (District-wide)	*Learning Odyssey* PowerPoint presentation	Develop understanding of the interaction of fundamental and derived science literacy
Workshop 8	Visual literacy	Emphasize visual representations	Read and create labelled photographs and flow diagrams
Workshop 9	Visual literacy Genre writing	Create posters and PowerPoint presentations	Develop alternative methods to assess understanding of science concepts
		Year 3 (2007–2008): Building a repertoire	
Workshop 10	Genre writing	Guided inquiry with pillbugs	Use inquiry as a springboard into writing a variety of science genres: argument, description, instructions, and explanation
Workshop 11	Reading comprehension	THIEVES	Use a prereading strategy to improve comprehension

	Genre writing	Informational brochures	Integrate visual and print elements Develop confidence implementing a common science genre
Workshop 12	Visual literacy	Functions of visual elements	Identify functions of visual elements Use functions to create visuals that enhance understanding
Workshop 13	Visual literacy	Assessment of visual elements	Establish criteria and develop rubrics for diagrams, tables, graphs, etc.
Workshop 14	Genre writing	Unification of rubrics for informational genres	Establish a framework for assessing a range of multimodal informational genres (e.g., posters, PowerPoint presentations, brochures)
Year 4 (2008–2009): Developing lead teachers			
Workshop 15	Vocabulary/ Concepts Visual literacy Reading comprehension	Foldables®	Introduce a teaching strategy (using Foldables) that uses visual and written information Incorporate Foldables into unit planning
Workshop 16	Oracy	Argumentation Part 1	Develop understanding of the aspects of argumentation
Workshop 17	Oracy	Argumentation Part 2	Incorporate argumentation into mandated units
Workshop 18	Vocabulary acquisition Genre writing	Sharing of strategies Mystery Powders	Establish a repertoire of vocabulary acquisition strategies Identify aspects of laboratory reports
Year 5 (2009–2010): Developing and disseminating resources			
Summer Planning Sessions	Literacy strategies with cross-curricular utility	Create a resource for district-wide dissemination	Select strategies and determine format of presentation Finish purposeful embedding of strategies in science units
Presentation Day 1	School A School B School C	THIEVES Vocabulary acquisition Foldables	Present three literacy strategies in an interactive school-based workshop for content area teachers
Presentation Day 2	School A School B School C	Argumentation Informational brochures and posters Concept mapping	Present three literacy strategies in an interactive school-based workshop for content area teachers
District-wide K-12 Conference		Foldables Informational brochures and posters THIEVES Argumentation	Present literacy strategies to a wider audience (more schools and extended grade range)

The progression of the project is summarized as Year 1 – Exploring the Problem Space, Years 2 and 3 – Building a Repertoire, Year 4 – Developing Lead Teachers, and

Year 5 – Developing and Disseminating Resources (Van der Flier-Keller, Anthony, Tippett, & Stege, 2010). During the project, the number of participants fluctuated (see Figure 25) as a result of "competing priorities within the school districts and schools, retirements, maternity leaves, staffing changes, and the relocation of one school" (Anthony et al., 2010, p. 55), and the format of the workshops changed from drop-in to a year-long commitment.

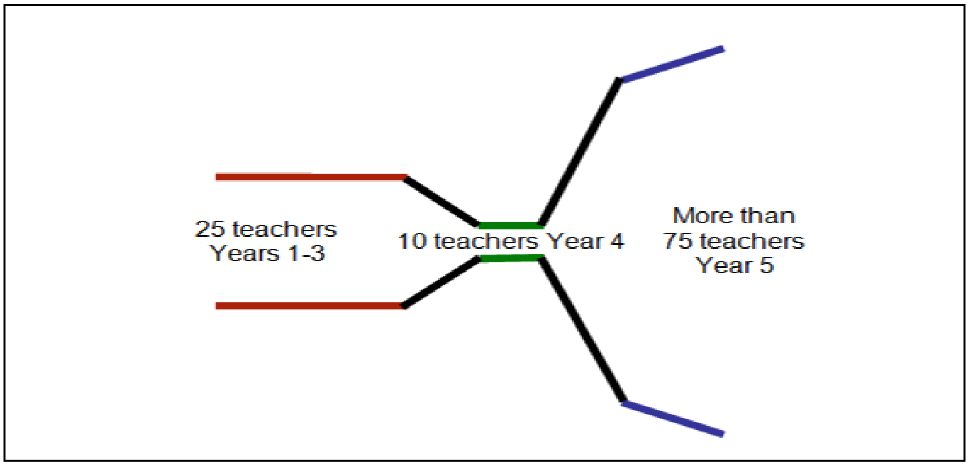


Figure 25. Number of participating teachers throughout the course of the project.

Case 1: Informational Brochures

Due to the collaborative nature of the project, the workshop schedule reflected teachers' interests and students' needs although responsibility for delivery of professional development shifted from teachers to researchers. The community-based design meant that the agenda shifted from the researchers' initial emphasis on science inquiry approaches, learning cycles, and specific literacy strategies to the teachers' focus on the strategies that they perceived to be the most effective and practical within the constraints of their classrooms. Visual literacy strategies were the focus of several workshops in Year 2; in subsequent workshops, teachers expressed a need for support with assessing students' multimedia work and, in particular, for assessing informational posters (Anthony et al., 2010).

In the following sections, I describe four case studies that I conducted during Years 3, 4, and 5 of the Pacific CRYSTAL project. The cases are presented in chronological order, and the subsequent case-to-case synthesis follows a common format; a within-case analysis of each case followed by a cross-case analysis (Cresswell, 1998).

In this case study, we utilized a writing-to-learn approach so that students would learn about a specific science reading and writing genre, which would strengthen fundamental literacy and scientific understanding (Tippett, Yore, & Anthony, 2008). Reports—a traditional genre of scientific writing—contain rich descriptions, are written in response to authentic questions, rely on a variety of sources of information, and require synthesis of second-hand information (Keys, 1999). We identified several alternate yet authentic genres that met these requirements and selected the informational brochure as a genre that students could use to enhance, consolidate, and demonstrate scientific understanding. Questions guiding our research included: *How does the creation of informational brochures impact the subsequent comprehension and interpretation of novel science concepts that are presented in a brochure format? How effectively can students demonstrate their understanding of science concepts using the brochure format? Does the brochure format allow all students to access and represent information, regardless of academic ability?*

After a workshop on informational brochures during which the genre was introduced and teachers worked in grade groups to create their own templates for use with specific science topics, we observed teachers implementing the activity and we observed students in the process of creating brochures. We collected samples of students' completed brochures and teachers answered a semistructured questionnaire on the effectiveness of the strategy. We conducted a nonrandomized control group posttest-only comparison. A brochure on bridges, a topic not included in the British Columbia middle school science curriculum, was prepared as a model for instruction. Teachers asked students to read the bridge brochure and then answer ten questions (multiple choice and short answer) based on the information contained in the brochure.

Results and Implications

Initial teacher response to the activity was positive: at the introductory workshop, all eight teachers in attendance reported that they would use brochures with their science classes and all teachers have since implemented the strategy. Teachers were able to adapt the activity to match their personal teaching styles and at the same time meet the needs of a diverse group of students. Several teachers incorporated ICT (another fundamental aspect of scientific literacy) into their science instruction utilizing readily available software and hardware. The brochure activity was used with a variety of prescribed science topics as well as in other subject areas. Teachers reported that students seemed enthusiastic about creating brochures, with an unusually high percentage of homework assignments handed in on time; and the brochure assignment was seen as manageable for all students, even those students with Individualized Education Plans.

Students with a range of learning needs were able to produce brochures that met the criteria for the assignment. An inspection of the students' brochures revealed that students were able to use visual representations (hand drawn or selected from images available on the internet) in decorational, representational, and organizational functions (Carney & Levin, 2002). These representations were sometimes, but not always, integrated with the written information. The completed brochures indicated differing levels of understanding of science concepts, and teachers deemed those levels as consistent with or superior to their expectations, based on previous student work.

Examining the results from three nonrandom treatment groups and a comparison group indicated that classes in which Grade 7 students had the opportunity to produce brochures tended to score higher on a multiple choice-short answer quiz than classes in which students had not yet created their own brochures, as shown in Table 9 (Anthony et al., 2010). Students who had not created their own brochures were more likely to be confused by the conventions of the brochure format, as indicated by their questions about how to read the brochure; there were no questions about how to read the brochure in classes in which students had created their own brochures. Students who were familiar with the genre appeared able to focus on the information, thus using a fundamental aspect of science literacy (reading in science) to learn a derived aspect (science content).

Writing in the brochure genre enabled students to demonstrate their understanding of science concepts in a format requiring higher level thinking processes such as synthesis. Creating brochures required students to identify main ideas and supporting details as space restrictions meant that words and visual representations had to be selected to convey information as efficiently as possible. It appeared that when middle school students participated in an authentic science writing task, such as creating brochures,

Table 9

Number of students correctly answering questions on information in a brochure

	Students	Quiz question number									
	n	1	2	3	4	5	6	7	8	9	10
Class A	21	20	20	20	20	10	16	17	18	11	21
Class B	21	21	20	21	19	11	18	17	19	9	21
Class C	21	18	20	20	18*	9*	15	19	21	10	21
Comparison class	21	18	18	19	19	10	15	16	18	8	21

*Results were lower than those of the comparison class.

they were highly motivated. In this case, students designed personalized and creative artefacts that revealed an understanding of the brochure genre as well as of the science concepts upon which those brochures were based.

Case 2: Middle School Students Use Informational Posters and Foldables® to Demonstrate Understanding of Science Concepts

This case study explored students' use of two multimedia formats to demonstrate understanding of science concepts: Foldables® and informational posters (Tippett & Yore, 2009a). Foldables are 3D graphic organizers that students create by cutting and folding paper in a variety of formats and then adding words and visual representations. Foldables can be used as tools for constructing knowledge and communicating learning; and they provide a structure for organizing concepts, summarizing main ideas, and visually representing information. The limited space provided by Foldables encourages students to communicate concisely using graphs, tables, charts, diagrams, models, and/or Venn diagrams along with written text.

The questions guiding this case study were: *How well can students in Grade 6 use a multimedia combination of writing and visual representations to demonstrate an understanding of science concepts? What multimedia instructional strategies lead to improved student comprehension of science concepts? When Grade 6 students create multimedia, are there motivational, attitudinal, or cognitive effects? Which strategies can be used with a range of science topics as well as in other subject areas?*

The case study examined activities in one Grade 6 classroom during a unit on Diversity of Life. At specific points throughout the unit, students were required to create Foldables to record and organize concepts. At the end of the unit, students created an informational poster, containing Foldables and a labelled diagram, to demonstrate their understanding of the unit concepts. The students presented their posters to the class and invited other classes to participate in a gallery walk, which meant that the students were writing to communicate with a broader audience and not just the classroom teacher.

The teacher and nine students were interviewed about the end-of-unit posters and about the use of Foldables. The questions for the students' semistructured interviews are shown in Table 10.

Table 10
Students' Semistructured Interview Questions about Foldables® Posters

1. Tell me a little about your poster.
2. How did you decide which Foldables to use?
3. Did you enjoy working on the poster? Why or why not?
4. What was your favourite part of the poster project? Why?
5. What was your least favourite part of the poster project? Why?
6. How did you decide what pictures to use?
7. What one thing are you especially proud of?

Results and Implications

Student responses during semistructured interviews revealed some themes in student use of multimedia formats (Tippett & Yore, 2009a). The informational posters and Foldables were perceived as novel and, therefore, as more interesting and engaging than the more traditional approaches to assessment in science, such as written reports or unit tests. It is not clear whether the novelty would eventually wear off, rendering the multimedia approaches less motivating. During this case study, the tasks were engaging for most students, who were able to adapt the formats in a variety of ways to suit their particular communication needs. Students reported Foldables as being especially helpful in studying for quizzes and tests because important concepts and relationships were clearly organized. Students also reported a preference for creating informational posters over completing traditional end-of-unit tests, despite the greater amount of time and effort required to complete the posters. Students with significant learning needs were able to successfully complete both informational posters and Foldables.

From the classroom teachers' perspective, the multimedia activities provided powerful learning opportunities. Ms. Brown[9] stated, *I think more learning occurred while students were preparing the posters than if they had been studying for a test. There was lots of teacher-student interaction and lots of science talk happening.* In addition, teachers noted that students appeared to have a more positive attitude about the poster project than would be expected if they were writing a report or studying for a test. Informal focus groups revealed that after informational posters and Foldables were presented during professional development workshops, both multimedia approaches were enthusiastically adopted by the teachers, who indicated that the approaches would become part of their permanent repertoire of teaching strategies. In fact, several teachers had implemented Foldables in other content areas, including mathematics and social studies. Teachers adapted both activities to match their teaching style and to accommodate the learning needs of a diverse group of students. Teachers deemed informational posters as valid summative assessment measures while Foldables were seen as useful for formative and summative assessment.

Case 3: A Multimodal Science Unit

This descriptive case study provided an in-depth look at how one Grade 6 classroom teacher was influenced by her ongoing professional development community of learners. Our participant was selected through purposeful sampling; we believed the unit taught by Ms. Brown could be viewed as a critical case (Polkinghorne, 2005). Although some teachers had been part of the professional development learning community since the beginning of the project, Ms. Brown was a new participant, joining in Year 4 when she was assigned to teach at a school where the project needed further representation. Ms. Brown was briefly introduced to the strategies and ideas that had been presented in the preceding two years, and she attended the four workshops held during the 2008–2009 school year (Tippett & Yore, 2010).

Because there was an established sense of trust and respect between researchers and teachers, Ms. Brown was willing to extend an open invitation to observe her science

[9] All names are pseudonyms, which were chosen to reflect the gender of the participant.

classes at any time. The unit that provided the basis of the case study was Extreme Environments, a provincially mandated topic. The questions guiding this study were: *What impact did the professional development project have on participating teachers? How did Ms. Brown's experiences as a participant in the professional development project influence her approach to teaching science?*

Data collection for this research project was qualitative: field notes during classroom observations, semistructured interviews with Ms. Brown and with her students, and artefacts such as Ms. Brown's planning notes and student products. A qualitative analysis of the interviews and the field notes revealed overarching themes in Ms. Brown's teaching, and a member check ascertained that Ms. Brown agreed with the authors' identification of those themes, thus ensuring credibility. Student artefacts were analyzed for the use of visual representations.

Results and Implications

Despite missing the formal presentation of many of the literacy strategies, Ms. Brown still incorporated almost all of the strategies in her classroom instruction. In fact, the only strategy that Ms. Brown did not use during the focus unit was concept mapping although she did incorporate a mystery map (Black Cockatoo, 2006) in the next unit she taught. The focus strategies were identified in Ms. Brown's Extreme Environment unit overview, and I observed the implementation of those strategies during classroom visits. Table 11 provides an overview of the Extreme Environments unit planned and taught by Ms. Brown.

Ms. Brown began the unit using the THIEVES prereading strategy (Manz, 2002), which provided her students with an overview of the information contained in the textbook. She used the textbook to provide a structure for her unit, but she did not feel constrained to follow the order of presentation nor to address all subtopics. Where appropriate, Ms. Brown embedded multimodal strategies (e.g., Foldables, Zike, 2001) where students used written text and visual representations to record information and communicate their learning. Labelled diagrams, a common visual representation in science textbooks as well as in academic science communication, were a required component of one particular Foldable. Students had opportunities for hands-on investigation; and although those investigations tended to be teacher structured, student

Table 11

A Multimodal Grade 6 Extreme Environments Unit

Day	Activity	Pro-D influence
	Features of extreme environments	
1	☞View video clips of extreme environments and discuss features ☞Complete K and W columns of KWL table	☞Visual representations
2	☞In groups, use the THIEVES prereading strategy to overview the unit	☞Reading comprehension (THIEVES strategy)
3	☞Read relevant pages in the textbook and complete chart	☞Vocabulary development
4–6	☞Create mini-matchbook Foldables® for four extreme environments: front = labelled diagram, inside top = features, inside bottom = challenges	☞Foldables strategy ☞Labelled diagrams ☞Rubrics
	Technologies used in extreme environments	
7	☞Groups read specific sections of the textbook and report back to the class	
8	☞Read about specific Canadian contributions and make notes on chart ☞Complete a rough draft of a labelled diagram	☞Labelled diagrams
9–12	☞Use notes and diagrams from Days 7-8 to create an index tab Foldable on Canadian technologies	☞Foldables strategy ☞Labelled diagrams ☞Rubrics
13	☞Review for quiz	
14	☞Quiz (regular and adapted versions)	
	Hands-on investigation: Testing materials for a polar suit	
15	☞As a class, develop question and hypothesis ☞Homework: think of a procedure	
16	☞Discuss possible procedures and establish steps	
17	☞Conduct experiment in groups, each group testing a different material ☞Discuss findings and reach consensus	☞Argumentation
18	☞Write up experiment: question, hypothesis, actual procedure, diagram, analysis of results, conclusion, and application	☞Writing genres (laboratory report) ☞Labelled diagrams
	Final project	
19–20	☞Select project and topic; use planning sheet ☞Research topic in library and record bibliographic information on sheet	☞Visual representations ☞Writing genres
21–23	☞Work on projects (individually or in pairs)	
24–28	☞Present projects to class	

input was solicited for developing the procedures. Although Ms. Brown felt she did not formally incorporate argumentation, she did initiate a number of discussions in which pros and cons of a particular solution or idea were presented. Instead of an end-of unit test, Ms. Brown assigned her students an end-of-unit project. Students were required to demonstrate their understanding of a particular extreme environment by preparing and presenting a poster, a board game, a PowerPoint presentation, a 3D model, or a newspaper. Students were able to work individually or with a partner as they prepared their multimodal projects, and the class produced a total of 15 end-of-unit projects: 5 PowerPoint presentations, 5 games, 2 newspapers, 2 posters, and 1 model. All 15 projects utilized visual representations to some extent; even the model and the board games had accompanying pictures. It was clear that the unit that Ms. Brown planned and taught was more innovative than traditional. The textbook served as a guide rather than the sole source of information; and although students answered questions from the textbook, Ms. Brown selected questions that emphasized higher level thinking rather than factual recall.

Students participated in hands-on activities and were asked to demonstrate their understanding of science concepts in a variety of ways. However, examining planning documents and analyzing field notes about classroom observations provide only a snapshot of Ms. Brown's classroom practice and do not indicate what factors may have influenced that practice. In order to examine the impact of Ms. Brown's participation in the professional development learning community, we conducted several semistructured interviews with Ms. Brown. Previous classroom observations and teachers' self-reports indicated that the literacy strategies presented at professional development workshops were appropriate for use with a variety of science topics and most could be easily adapted for Grades 6, 7, and 8 students with a range of learning needs (Anthony et al., 2010; Tippett et al., 2008). Ms. Brown agreed, noting that she believed each strategy might be used with all three of the Grade 6 science topics (Electricity, Diversity of Life, and Extreme Environments) and that she had used informational brochures with her Grade 8 Social Studies class.

Ms. Brown commented on the assessment opportunities that particular approaches afforded her. Rather than hoping she had asked appropriate questions on a quiz or end-of-unit test, she was able to assign multimedia projects in which students were requested to show everything they knew. Ms. Brown believed that the resulting Foldables and posters were very revealing, and she felt that student misunderstandings were more obvious in these formats than they would be in a pencil-and-paper test.

An aspect of membership in an ongoing professional development community that Ms. Brown found especially powerful was the opportunity to revisit teaching strategies. Rather than a single instance workshop that might be inspiring yet not influence her practice in a significant way, the ongoing nature and community control of this project meant that Ms. Brown could implement a strategy, share the results of the implementation with members of her learning community, and reflect both publically and privately on her practice.

Ms. Brown emphasized that had she not been a member of the professional development learning community, her planning and teaching would have been radically different: *I would have basically followed the teachers' guide, which was a lot of 'read this section and answer questions'.* Instead, Ms. Brown incorporated a range of innovative literacy strategies that represented the nature of the discipline of science, which she believed resulted in a more authentic and engaging learning experience for her students.

Case 4: Creating a Professional Development Resource

The final case study to be included in the case-to-case synthesis describes the creation of a professional development resource that was based on participants' experiences during the *Explicit Literacy Instruction Embedded in Middle School Science* project. In Year 4 of the project, participation was limited to 10 lead teachers who attended all workshops and were willing to become professional development facilitators in Year 5. The focus of the workshops shifted to include planning, with the previously introduced literacy activities being purposefully embedded into all mandated science units for Grades 6, 7, and 8—an opportunistic approach to curriculum development. In the summer between Years 4 and 5, eight of the lead teachers met to prepare an instructional resource that would be disseminated to all content area middle school teachers in the district (Tippett & Yore, 2010). Questions guiding this reflective case study included: *How were strategies selected for inclusion in the instructional resource? What aspects of the professional development project were seen as important, and why?*

Results and Implications

Each of the teachers who participated in the summer working group had had an opportunity to implement, reflect on, revise, and re-implement a number of literacy strategies that had been presented during the four years of the *Explicit Literacy Instruction Embedded in Middle School Science* project. All teachers were asked to respond to a brief survey about those strategies (see Figure 26), the results of which informed the selection of the strategies to be included in the instructional resource. As a group, the teachers discussed the benefits and challenges of those strategies that a majority of the teachers rated as high in effectiveness. The group also considered the cross-curricular applicability of each strategy because strategies had initially been chosen to represent the discipline of science.

Additional considerations included school and district goals, ease of implementation, and of course, effectiveness in increasing science literacy for all students. Identifying the six strategies or techniques to be included in the instructional resource was a fairly simple process because teachers either strongly agreed with the inclusion of a particular strategy or did not disagree that a strategy should be included. The teaching strategies that we agreed upon were: THIEVES (Manz, 2002), vocabulary acquisition, Foldables (Zike, 2001)®, argumentation, informational brochures and posters, and concept mapping. Deciding on the order of presentation was another simple process because we unanimously agreed to reflect the order in which each activity might occur in a typical unit, although each approach could be used at almost any time during a unit.
Decisions about the actual design of the resource were not as simply made, however. As might be anticipated, each of the teachers involved in the working group creating the instructional resource had a slightly different view of what the finished product might entail, as did the researchers. I facilitated discussions between the teachers and mediated the negotiations between the working group and lead researchers. Ultimately, a common format was accepted as reasonable by all members. The handbook was to be composed of three parts:

- Part 1 would be a **guide** containing descriptions, rationales, key features/functions, connections to science goals, ideas for implementations, cross-curricular connections, interactive whiteboard connections, and ideas for assessment as well as student samples, related articles, blackline masters, and references for each of the six strategies.

Pacific CRYSTAL Literacy Strategies in Middle School Science

Strategy Implementation Survey (2008-2009)

Name: ________________________ School/Grade: _________________________

Class Description: ____

____

____

Literacy Strategy	Number of times used	Effectiveness	Comments and Suggestions
THIEVES	0 - 1 - 2 - 3 - 4 - 5	low - average - high	
Concept Maps	0 - 1 - 2 - 3 - 4 - 5	low - average - high	
Argumentation	0 - 1 - 2 - 3 - 4 - 5	low - average - high	
Foldables	0 - 1 - 2 - 3 - 4 - 5	low - average - high	
Brochures	0 - 1 - 2 - 3 - 4 - 5	low - average - high	
Posters	0 - 1 - 2 - 3 - 4 - 5	low - average - high	
Vocab: _________	0 - 1 - 2 - 3 - 4 - 5	low - average - high	
Vocab: _________	0 - 1 - 2 - 3 - 4 - 5	low - average - high	
Vocab: _________	0 - 1 - 2 - 3 - 4 - 5	low - average - high	
Labelled Diagrams	0 - 1 - 2 - 3 - 4 - 5	low - average - high	
Cross-sections	0 - 1 - 2 - 3 - 4 - 5	low - average - high	
Flow charts	0 - 1 - 2 - 3 - 4 - 5	low - average - high	
Other: __________	0 - 1 - 2 - 3 - 4 - 5	low - average - high	
Other: __________	0 - 1 - 2 - 3 - 4 - 5	low - average - high	
Other: __________	0 - 1 - 2 - 3 - 4 - 5	low - average - high	

Figure 26. Strategy implementation survey completed by teachers in the summer working group.

- Part 2 would include **sample instructional frameworks** for Grades 6, 7, and 8 science units that would illustrate some of the ways in which these literacy strategies could be used in combination with science activities to meet the Prescribed Learning Outcomes (PLOs) contained in the *Science K to 7: IRP* (Ministry of Education, 2005) and the *Science 8: IRP* (Ministry of Education, 2006b).
- Part 3 would be a **CD** that contained Parts 1 and 2 in electronic form with student samples shown in colour. The CD would also contain academic articles about the strategies as well as PowerPoint presentations that may be shown to students. All blackline masters included on the CD were formatted so that they could be adapted to suit particular activities and/or students or used with technology such as interactive whiteboards.

Teachers worked in small grade groups to prepare the sample instructional frameworks. Although science textbooks were used as a structure for planning, teachers drew on their pedagogical expertise and previous experiences to develop a sequence of activities that would address the PLOs. Each unit also incorporated each of the six literacy strategies one or more times, to show how the strategies could be embedded.

Because the intent was to make the resource teacher friendly, the finished product was housed in a binder so that additional resources could be easily added and so that blackline masters could be removed for ease of photocopying. A photograph of the completed instructional resource for middle school content area teachers is shown in Figure 27.

Two separate professional development workshops, each consisting of a PowerPoint presentation and several hands-on activities for three of the strategies, were created by the summer working group. Members of the group acted as facilitators during these workshops with support provided by the research team; and each school-based workshop was offered to all teachers, teaching assistants, and student teachers. The entire instructional resource has been presented and distributed to more than 100 teachers, teaching assistants, student teachers, and teachers-on-call (i.e., substitute teachers). In addition, portions of the binder were presented at a local professional development conference during two workshops that were attended by teachers of Grades 3-10.

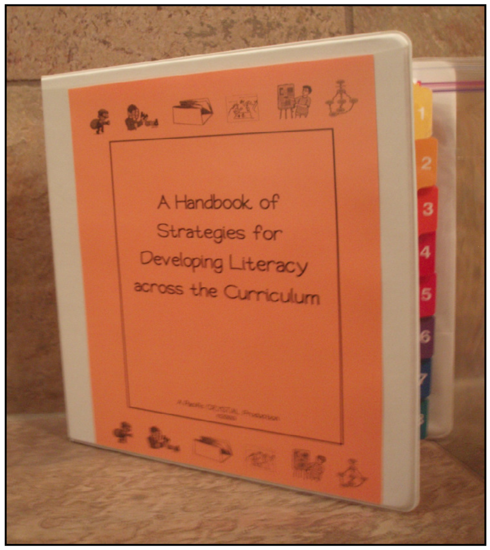


Figure 27. The completed instructional resource.

Overarching Themes in the Four Case Studies

As noted previously, the metasynthesis was influenced by my interest in the use of visual representations; but I actively sought evidence that might indicate the presence of broader themes that were unrelated to this interest and that might more completely reflect the fundamental sense of science literacy. Analyzing the cases in chronological order, I followed a process of constant comparison (Flick, 2002), using the themes that emerged from the first individual case study as foci for analyzing the second case study, reanalyzing the first case study using new themes that emerged from the analysis of the second study, and continued that process until I had analyzed all four case studies for the presence of all potential themes, as shown in Figure 28. Finally, I identified overarching themes for which there was supporting evidence from at least three of the four case studies, meaning that at least three of the six links shown in Figure 29 would be present.

Five overarching themes emerged from the case-to-case synthesis: the engaging and effective nature of multimedia genres, opportunities for differentiated instruction, opportunities for assessment, an emphasis on visual representations, and the robustness of the literacy strategies. Each of these themes is presented in the following sections with supporting evidence from relevant cases.

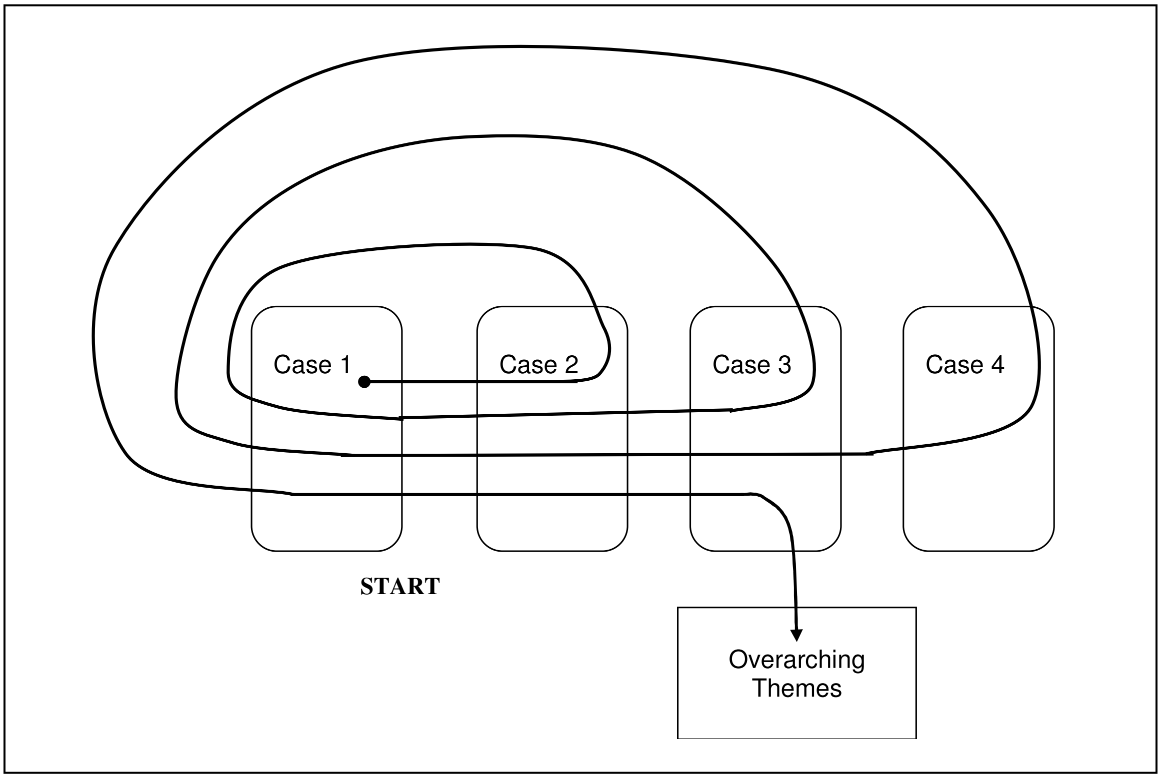


Figure 28. Path of the case-to-case analysis.

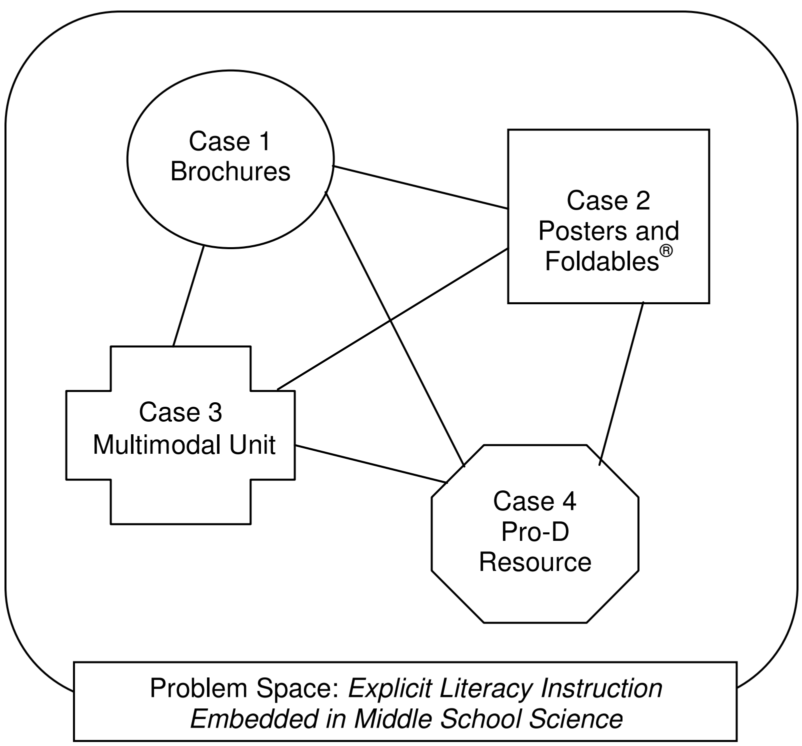


Figure 29. Potential links that might appear in the case-to-case synthesis.

Synthesis Theme 1: Multimedia Literacy Strategies can be Engaging and Effective

The teachers' enthusiasm about incorporating the multimedia literacy strategies in their science instruction, combined with the perceived novelty of the activities, meant that students were more than usually engaged in the activities. Evidence from the four case studies to support this claim includes:

- Students seemed enthusiastic about creating brochures, with an unusually high percentage of homework assignments handed in on time. (Case 1)
- Students who had experience with the brochure format seemed to have better comprehension of subsequent information presented in a brochure. (Case 1)
- Students preferred to demonstrate their understanding of science concepts by creating informational posters rather than writing traditional end-of-unit tests. One Grade 6 student noted, *It was much funner. It was hands-on where you did it yourself*. (Case 2)
- Students noted that Foldables helped them to remember concepts and relationships and teachers reported student success with use of these items as study aids. (Cases 2, 3, 4)
- Ms. Brown observed that students who ... *normally didn't put a lot of effort into their work were actually putting lots of effort into [their Foldables].* (Case 3)

It is not clear how long the multimedia activities would be perceived as novel and, therefore, more engaging and motivating than activities that were more familiar. One of the participating teachers did caution the summer planning group that incorporating too many Foldables eventually seemed to have a negative effect on his students' attitude toward the technique. It should be noted that, while a link between motivation and construction of knowledge might exist, none of the case studies were designed to explore such a link.

Synthesis Theme 2: Multimedia Projects Facilitate Differentiated Instruction

Teachers were particularly keen to incorporate strategies that they believed facilitated Differentiated Instruction (DI), a district initiative. DI occurs when teachers vary content, activities, products, and/or the learning environment to meet the needs of individual students (Tomlinson, 2000). DI fits with constructivist theory because prior knowledge and experience are considered influential in the acquisition of new information. DI accommodates student agency because students have opportunities to make choices that will benefit their learning. Evidence from the four case studies that supports the connection between the multimedia activities and DI includes:

- Students with a range of learning needs and prior experiences were able to produce informational brochures that met the criteria for the assignment. (Case 1)
- The formats and content of informational brochures, informational posters, and Foldables could be modified in a variety of ways to suit individual students' particular needs and abilities. (Cases 1, 2, 3, 4)
- Teachers adapted Foldables, informational poster, and informational brochure activities to match the needs of their students. Several teachers incorporated ICT in their instruction, which provided additional support for students. (Cases 1, 3, 4)
- Students who may not have been academically strong in science or other subject areas had a chance to shine in an academic context by using other abilities (e.g., kinaesthetic prowess) while working to create a science product. Ms. Brown remarked, *I had Foldables experts – I showed one or two students how to make certain kinds of Foldables, and if students wanted to use a Foldable, they went to see an expert.* This opportunity to act as a peer expert was often a novelty for these students. (Case 2)
- Multimedia projects such as informational brochures, Foldables, informational posters, and newspapers provided opportunities for more capable students to work at their own level. Ms. Brown noted, *They need those kinds of things where they can just go as deep as they want to …and they want to.* On the other hand, students with learning challenges were able to create products of which they were justifiably proud. (Case 3)
- Teachers decided to highlight the possibilities for DI in the instructional handbook. (Case 4)

The multimedia activities afforded teachers opportunities for DI because the products (Foldables, informational brochures, and informational posters) were easily adapted to meet the needs of a wide range of students. Student agency was reflected in the opportunities students had to make choices about how best to communicate their science understanding. Students could create individualized products that reflected their levels of understanding and ability. The flexibility of the multimedia products meant that teachers could vary content for those students with significant learning needs (e.g., students with Individualized Education Plans) in such a way that those students were able to create products that resembled other students' products and of which they were justifiably proud.

Synthesis Theme 3: Multimedia Projects Provide Opportunities for Assessment

Current assessment practices in British Columbia include assessment *for*, *as*, and *of* learning (Ministry of Education, 2005). These three types of assessment are used in combination to inform teaching and to support student achievement. Assessment *for* learning is formative assessment that provides information about students' progress; that information is subsequently used to modify teaching, connecting assessment and instruction. Assessment *as* learning occurs when students are actively involved in thinking about their own learning. Assessment *of* learning is summative assessment that typically occurs at the end of a unit or year of instruction; the information obtained is used to provide evidence of student achievement for the purposes of formal reporting.

Assessment in science using a combination of writing and visual representations reflects the nature of scientific discourse (Abell & Volkmann, 2006; USNRC, 1996; Shepardson & Britsch, 2001). Using multimedia activities for assessment means that assessment can be embedded within instructional situations rather than situated as a separate process. Teachers in the Pacific CRYSTAL project believed that multimedia texts could afford opportunities for assessment *for*, *as*, and *of* learning and provide greater insights into student understanding than traditional tests and quizzes. Evidence from the four case studies that supports the use of multimedia activities for authentic assessment *for* and *of* learning includes:

- The completed brochures indicated differing levels of understanding of science concepts, and teachers deemed those levels as consistent with or superior to their expectations based on previous student work. (Case 1)
- Informational posters were deemed valid summative assessment measures while Foldables were seen as useful for formative assessment. (Case 2)
- The applicability of multimedia formats for assessment was emphasized by Ms. Brown: *I could identify misconceptions or misinformation because it stood out right away, better than with a quiz.* (Case 3)

- All strategies selected for inclusion in the instructional resource were evaluated for their assessment opportunities because the ability to use an activity for assessment increased the usefulness of a strategy or techniques (Case 4)

The multimedia activities afforded opportunities for formative assessment (assessment *for* learning) and summative assessment (assessment *of* learning). The combination of visual and verbal information reflects the nature of scientific communication; therefore, the use of visual representations for assessment enhanced the authenticity of that assessment.

Synthesis Theme 4: Visual Representations are a Key Aspect of Science Instruction

Communicating, conceptualizing, and constructing meaning in science requires the use of a range of visual representations, including graphs, equations, and labelled diagrams. The conventions of these highly specialized representations must be learned by students who are at the same time learning the concepts being represented. Participating teachers believed that visual representations should be an important aspect of their science instruction. Evidence from the four case studies that indicated the key role of visual representations in science includes:

- The multimedia genres were positively assessed by teachers who remarked on the options for creativity, the use of kinaesthetic and aesthetic talents to attain some success in science, and the appropriateness for students with learning challenges. (Cases 1, 2, 3, 4)
- Ms. Brown incorporated explicit instruction about labelled diagrams into her science projects because she had found that students typically needed support with how to read and create these visual representations. (Case 3)
- All six literacy strategies that were chosen for inclusion in the handbook had a visual representation component—even argumentation, for which a teaching approach using concept cartoons was described. (Case 4)

The results of the literature review presented in Chapter 2 indicated the need for explicit instruction regarding the conventions of visual representations (e.g., Pintó & Amettler, 2002; Prain & Waldrip, 2006). Knowing the conventions of representations is an important aspect of representational competence, and increased representational competence should facilitate comprehension of science concepts and increased science literacy. Participating teachers believed that visual representations played an important role in science as revealed by their interest in the multimedia strategies that were presented during professional development workshops, by their implementation of those strategies within a range of units, and by their explicit instruction regarding conventions of representations.

Synthesis Theme 5: Literacy Strategies can be Robust across Topics and Subjects

Shanahan and Shanahan (2008) conceptualized literacy as consisting of three stages: basic, intermediate, and disciplinary. Middle school science students might be expected to have mastered basic literacy abilities (e.g., decoding strategies and a repertoire of sight words), to have acquired some intermediate abilities (e.g., generic comprehension strategies), and to be working towards some disciplinary abilities (e.g., constructing and communicating scientific ideas using a combination of visual and verbal information). The science literacy strategies that were introduced to participating teachers could be considered as straddling the border between intermediate and disciplinary literacy; as a result, those strategies were transferable across a range of science units and within several other content areas, such as mathematics and social studies. Evidence from the four case studies that supports this claim includes:

- At least three of the teachers who used informational brochures in science also used the brochure activity in social studies. (Case 1)
- Foldables were used with a variety of science topics as well as in other subject areas including social studies, language arts, and mathematics. (Cases 2, 4)
- The six strategies selected for the instructional handbook were chosen based on their applicability with a range of science topics and their suitability for use with other content areas. (Case 4)
- The THIEVES reading strategy and the use of informational brochures, informational posters, and Foldables were enthusiastically adopted by teachers who indicated that these approaches would become part of their permanent repertoire of teaching strategies. Teachers were observed using these strategies from unit to unit and year to year. (Cases 2, 3, 4)

Middle school science students are typically immersed in intermediate literacy practices and are beginning to acquire some disciplinary literacy abilities. Activities that emphasize generic literacy are appropriate for students at this level although those activities should also incorporate some aspects of disciplinary literacy. Such strategies as students using informational brochures and posters to demonstrate understanding require generic literacy strategies, including locating main ideas and supporting details, while the inclusion of visual representations builds on disciplinary literacy; visuals play a critical role in science discourse/Discourse (Gee, 2005; Lemke, 2003; Moje et al., 2001).

Implications of the Case-to-case Synthesis

The scope of the five themes that emerged from the case-to-case synthesis is broader than simply learning with visual representations because the themes include assessment, affective impact, and robustness of strategies. This broadened scope is an indication that my research bias was mitigated to some extent during the metasynthesis.

Some of the case-to-case synthesis themes are similar to themes of current research examining visual representations in science that were discussed in the literature review. For example, learning with visual representations, the importance of visual representations in science, and opportunities for assessment afforded by visual representations were aspects common to both the metasynthesis and the review.

The case-to-case synthesis revealed some important considerations for future classroom-based research. While most multiple representation or multimedia research has focused on cognition, it is clear that the affective and psychomotor domains should also be investigated. The assessment opportunities afforded by students' multimedia projects would be a fruitful area for further research, particularly with regard to more authentic assessment of levels of understanding and acquisition of skills for all students.

The metasynthesis yielded points that were considered when I was developing the proposed theoretical framework that I presented in the previous chapter. Classroom instruction that leads to enhanced science literacy for all students should include visual representations and is likely to require a multiliteracies approach because scientific communication is a multimodal process that involves reading, writing, speaking, listening, viewing, and representing (New London Group, 1996). The specifics of that instruction are not yet well documented in the science education literature; this could be attributed to the lack of a comprehensive theoretical framework that has explanatory power when students are creating or interpreting visual representations, whether the representations are static or dynamic.

Current cognitive theories of learning from multimedia texts do not fully address the complexities of classroom learning and teaching, such as the need for explicit instruction, social construction of representations, and learner-generated representations. The literature review and the case-to-case synthesis highlight areas that must be included in a theoretical framework that is comprehensive enough to be used with classroom-based research where students are learning with representations rather than learning from representations. A description of the development of an exploratory framework that holds explanatory power for learning with visual representations, whether those representations are static or animated, was provided in the previous chapter. This exploratory framework influenced the design and implementation of the classroom-based verification study that is described in Chapters 5 and 6.

Chapter 5
Methodology

This chapter opens by positioning mixed-methods research as an emerging methodology that encompasses aspects of both qualitative and quantitative research methodologies. A more specific definition of mixed-methods research is developed, and the rationale for choosing mixed methods as the research approach for the verification study is provided. Finally, the design of the verification case study is described in detail.

Mixed-methods Research: Development and Definition

Much of the research conducted in the early 20th century was quantitative in nature and based on positivist philosophy (Tashakkori & Teddlie, 1998). By the 1960s, however, postpositivism was the dominant research philosophy because many researchers had become critical of various aspects of positivism (Tashakkori & Teddlie, 1998). While postpositivist methods remained almost exclusively quantitative, the postpositivist perspective acknowledged that inquiry was value-laden and that reality was probable rather than certain. In fact, the postpositivist perspective paved the way for mixed-methods approaches (Denzin, Lincoln, & Giardina, 2006). During the 1970s, the constructivist paradigm[10] and its associated qualitative approaches gained popularity, leading to the qualitative/quantitative debate, otherwise known as the incompatibility thesis or the paradigm wars (Tashakkori & Teddlie, 1998). The debate raged for three decades; but while many scholars argued for the separateness (and superiority) of one approach or the other, some scholars proposed a third research paradigm, based on pragmatism, in which methodologies were combined: mixed-methods research (Creswell & Plano Clark, 2007). The incompatibility thesis has largely been discredited (Teddlie & Tashakkori, 2003), and most social science scholars now agree that research methods should be chosen to match the problem or phenomenon under investigation rather than to match a particular paradigm or philosophical bias (Tashakkori & Creswell, 2007).

Numerous definitions of mixed-methods research have been proposed. Johnson, Onwuegbuzie, and Turner (2007) presented 19 definitions, discussed five themes

---

[10] The term *paradigm* is consistent with usage in mixed methods literature (e.g., Levin & Wagner, 2009; Tashakkori & Creswell, 2007).

emerging from those definitions (what is mixed, when the mixing occurs, breadth of mixed research, why mixing is carried out, and the orientation of the research), and then proposed yet another definition. Although I could have simply reworded that definition, I decided instead to develop my own working definition of mixed-methods research and at the same time heighten my understanding of important themes in mixed-methods literature. I used open coding (Flick, 2002) to analyze and synthesize five definitions from sources that I considered credible and significant. I selected Tashakkori and Teddlie (1998), for example, because both authors have published articles, chapters, and books on mixed-methods research. First, I identified key elements of each definition, which are shown shaded in Table 12. Next, I rearranged the key elements into themes and developed a label for each theme, as shown in Table 13. Finally, I used those labels, shown in boldface in Table 14, to craft a working definition of mixed-methods research. The resulting definition is:

> Mixed-methods research involves the purposeful and systematic integration of qualitative and quantitative approaches, either in a single study or in sequential studies. The integration can occur during any or all phases of research: data collection, analysis, and/or inference (interpretation). The underlying philosophy of the mixed-methods research paradigm is considered to be pragmatism although some mixed-methods researchers label themselves a-paradigmatic. Mixed-methods research, because it is inclusive of a range of methodological traditions, can often provide more informative and insightful answers to research questions than purely quantitative or qualitative research can; some experts (e.g., Johnson et al., 2007) claim that mixed-methods research has the potential to generate both answers *and* questions.

In the following sections, the verification study is described in detail. The rationale for selecting a mixed-methods approach for the study and a description of the particular research design are provided. The specific data collection and data analysis methods implemented during the study are then presented.

Table 12

Step 1: Identifying Elements of Five Key Definitions of Mixed-methods Research

Tashakkori and Teddlie (1998, pp. 17-18):
Mixed method studies are those that combine the qualitative and quantitative approaches into the research methodology of a single study or multiphased study.

Creswell (2003, pp. 19-20):
[A] mixed-methods approach is one in which the researcher tends to base knowledge claims on pragmatic grounds (e.g., consequence oriented, problem-centered, and pluralistic)- It employs strategies of inquiry that involve collecting data either simultaneously or sequentially to best understand research problems. The data collection also involves gathering both numeric information (e.g., on instruments) as well as text information (e.g., on interviews) so that the final database represents both quantitative and qualitative information.

Greene (2005, p. 207):
A mixed method approach to educational and social inquiry is … an important counterpoint to the contemporary debate about what constitutes valid, rigorous, and 'scientific' research. By welcoming all legitimate methodological traditions, mixed method inquiry meaningfully engages with difference and thus offers some generative potential for better, enriched, more insightful understanding.

Creswell and Plano Clark (2007, p. 5):
Mixed methods research is a research design with philosophical assumptions as well as methods of inquiry. As a methodology, it involves philosophical assumptions that guide the direction of the collection and analysis of data and the mixture of qualitative and quantitative approaches in many phases in the research process. As a method, it focuses on collecting, analyzing, and mixing both quantitative and qualitative data in a single study or series of studies. Its central premise is that the use of quantitative and qualitative approaches in combination provides a better understanding of research problems than either approach alone.

Johnson, Onwuegbuzie, and Turner (2007, p. 129):
Mixed methods research is an intellectual and practical synthesis based on qualitative and quantitative research; it is the third methodological or research paradigm (along with qualitative and quantitative research). It recognizes the importance of traditional quantitative and qualitative research but also offers a powerful third paradigm choice that often will provide the most informative, complete, balanced, and useful research results. Mixed methods research is the research paradigm that (a) partners with the philosophy of pragmatism in one of its forms (left, right, middle); (b) follows the logic of mixed methods research (including the logic of the fundamental principle and any other useful logics imported from qualitative or quantitative research that are helpful for producing defensible and usable research findings); (c) relies on qualitative and quantitative viewpoints, data collection, analysis, and inference techniques combined according to the logic of mixed methods research to address one's research question(s); and (d) is cognizant, appreciative, and inclusive of local and broader sociopolitical realities, resources, and needs. Furthermore, the mixed methods research paradigm offers an important approach for generating important research questions and providing warranted answers to those questions.

Table 13

Step 2: Labelling Themes in Key Definitions of Mixed-methods Research

Key phrases	Theme
combine the qualitative and quantitative approaches synthesis based on qualitative and quantitative research	
single study or series of studies single study or multiphased study simultaneously or sequentially	Design: single or sequential
pragmatic philosophical assumptions pragmatism	Philosophy: pragmatism
collecting data collection and analysis of data data collection, analysis, and inference techniques collecting, analyzing, and mixing both quantitative and qualitative data	Data: collection, analysis, and inference
best understand research problems better, enriched, more insightful understanding a better understanding of research problems the most informative, complete, balanced, and useful research results providing warranted answers	Results: more informative and insightful
all legitimate methodological traditions cognizant, appreciative, and inclusive	Nature: inclusive of methodological traditions
generative generating important research questions	Potential: generate answers *and* questions

Table 14

Step 3: Crafting a Definition of Mixed-methods Research

Mixed-methods research involves the purposeful and systematic **integration** of qualitative and quantitative approaches, either in a **single** study or **sequential** studies. The integration can occur during any or all phases of research: data **collection**, **analysis**, and/or **inference** (interpretation). The underlying philosophy of the mixed-methods research paradigm is considered to be **pragmatism** although some mixed-methods researchers label themselves a-paradigmatic. Mixed-methods research, because it is **inclusive** of a range of **methodological traditions**, can often provide **more informative and insightful** answers to research questions than purely quantitative or qualitative research can; some experts (e.g., Johnson et al., 2007) claim that mixed-methods research has the potential to **generate** both **answers *and* questions**.

Appropriateness of the Mixed-methods Approach

The research approach selected for investigating a particular question should be determined by the nature of the question itself and by the nature of the problem space. Therefore, quantitative methods should be selected if they are likely to yield the most useful results (e.g., when testing hypotheses or verifying predictions), and qualitative methods should be selected if they are likely to result in the best description of the phenomenon being investigated. “Classroom research is messy” (Turner & Meyer, 2000, p. 69); in many cases, a mixed-methods approach is the best way to explore multiple variables from multiple perspectives (Nieswandt & McEneaney, 2009). In deciding whether a mixed-methods approach might be appropriate for investigating a particular issue, researchers should also consider the six principles of mixed-methods research shown in Table 15.

Table 15

Six Principles of Quality Mixed-methods Research

Fundamental Principle: Methods should be mixed in a way that has complementary strengths and no overlapping weaknesses.[a]
Second Principle: Mixing may occur in any stage of a study, from purpose/questions to data collection procedures, data analysis techniques, and the final inferences.[b]
Third Principle: Research design determines data collection procedures in mixed methods but is also independent of those procedures. Multiple data collection procedures might be used in both QUAN and QUAL strands of a mixed methods study.[b, c]
Fourth Principle: Data collection procedures are independent of data analysis techniques (e.g., data collected through observation may be analyzed two ways: QUAL and QUAN).[b]
Fifth Principle: If the data do not represent the theoretical phenomena or the attributes under study, then nothing else matters.[b]
Sixth Principle: Data quality is a necessary condition for inference quality but is not a sufficient condition for it. The criteria for evaluating the quality of the data and the quality of the inferences are not the same.[b]

Note. [a] Johnson & Turner, 2003, p. 299. [b] Tashakkori & Teddlie, 2003. [c] QUAN = quantitative and QUAL = qualitative.

An analysis of these principles revealed that a mixed-methods approach would be appropriate for exploring the problem space within which the dissertation is situated. The methods selected for data collection and analysis (detailed in the second half of this chapter) complement each other. Both qualitative and quantitative data collection and analysis techniques were identified as having the potential to provide the maximum amount of useful data, which would hopefully allow high-quality inferences to be generated. Methods of data analysis were not determined by whether the data were collected quantitatively or qualitatively; in the verification study, observations (a qualitative method of data collection) were analyzed both qualitatively (e.g., thematic coding) and quantitatively (e.g., comparisons of episode types during science instruction). The potential for examining a classroom-based case from several angles was a major factor in my decision to use a mixed-methods design for the verification study. A mixed-methods approach is useful when the problem space to be investigated is complex, as is the case with the dissertation research, because it offers "mindful flexibility" (Levin & Wagner, 2009, p. 217). The problem space surrounding learning with visual representations includes a collection of constructs in varying degrees of development, making a mixed-methods design an appropriative choice. The thematic review of recent research examining the use of visual representations in science, combined with the case-to-case synthesis, helped to identify areas of the problem space that were well developed and have been evaluated using quantitative methods and quasi-experimental design (e.g., factors in the comprehension of visual representations) and other areas that were not as well delineated and that require emergent explorations involving qualitative approaches (e.g., metacognitive aspects of creating visual representations).

Research Design

The particular mixed methods design selected for the verification study was a Triangulation Design (TD, see Figure 30). The TD incorporates qualitative and quantitative approaches to investigate a single phenomenon (Creswell & Plano Clark, 2007). Neither approach within the TD is more dominant than the other as the data collected using qualitative and quantitative approaches are analyzed as a whole to provide a better understanding of the original research question than either quantitative data or qualitative data collection and analyses might reveal separately (Creswell & Plano Clark, 2007). The TD is appropriate when the aim is to seek convergence of results (Nieswandt & McEneaney, 2009).

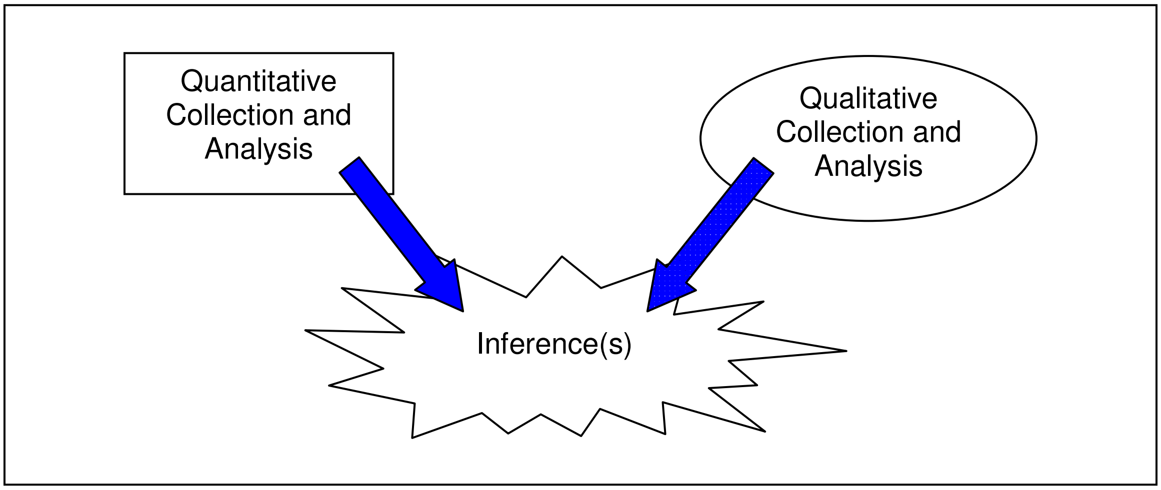


Figure 30. Basic Triangulation Design (Creswell & Plano Clark, 2007).

Mansour's (2007) exploration of the challenges faced by science teachers was a TD using data collected through questionnaires, interviews, field notes, and classroom observations and combining qualitative and statistical inferences. The verification study was planned to utilize similar qualitative data collection techniques and to incorporate quantitative data collection through drawing activities, multiple choice/short answer quizzes, and school-wide assessments of reading and writing achievement. In addition, both qualitative and quantitative analyses were planned because of the types of data that I collected or that were made available to me. Therefore, I selected the TD as the best fit for this project with qualitative and quantitative techniques being utilized simultaneously in both the collection and analysis of data. I anticipated that the TD would yield contextualized findings, which would in turn provide insights into the whys and hows of student-generated visual representations (Turner & Meyer, 2000).

The Verification Case Study

The verification study was a collective case study in the Pacific CRYSTAL *Explicit Literacy Instruction Embedded in Middle School Science* project. It was bounded by time and location (Cresswell, 1998), taking place throughout the first science unit of the 2009–2010 school year in two Grade 6 classrooms. A typical case study involves extensive data collection (Cresswell, 1998; Hays, 2004; Yin, 2009). In the verification study, I used multiple sources of information that reflected the theoretical framework and research context, including observations, audio recordings, interviews, reading and writing assessments, and documents. The question guiding the verification study was: *What happens when students in Grade 6 are asked to construct visual representations based on unfamiliar science information text, and how do these results relate to the exploratory framework?*

The Research Site

The verification study was conducted at a middle school in a public school district located in the Greater Victoria area. This school was selected for a number of reasons, including: (a) the concurrent participation of staff from this school in the umbrella Pacific CRYSTAL project (*Explicit Literacy Instruction Embedded in Middle School Science Classrooms*) with University of Victoria researchers; (b) my familiarity with the school, its administration, and the teachers; (c) previously obtained approval from the teachers, the principal, and the school district to conduct research at this school (see Appendix C for the principal's letter of support); and (d) the opportunity to use the results of previously conducted research within this school to contextualize the results of the dissertation.

Three elementary schools feed into this middle school, and the families served by the school represent a wide range of socioeconomic levels. The catchment area, with a total population of about 21,000 people, is a blend of heavy industry, scientific and technological enterprises, and residential areas. Some of the highest property values in the Capital Regional District are for homes in the surrounding neighbourhood. A First Nation community is located within the catchment area. Approximately 40% of the students come from single-parent families or blended families. During the 2009–2010 school year, the school had a total student population of 420, with 139 students in Grade 6, 120 students in Grade 7, and 161 students in Grade 8.

Description of Participants

The target population for this research project included both teachers and students. Teachers were recruited from the larger group of participants in the *Pacific CRYSTAL:*

Explicit Literacy Instruction Embedded in Middle School Science Classrooms professional development project that was described in detail in Chapter 4. These Grades 6, 7, and 8 generalist teachers of science from the school district's three middle schools had attended workshops that were held approximately every two months. The workshops emphasized opportunities for infusing literacy instruction into science education and included topics such as concept and vocabulary development (accessing prior knowledge, concept maps, etc.), reading comprehension (setting and monitoring purpose, detecting main ideas, summarizing, using text features, etc.), visual literacy (flow diagrams, labelled diagrams, etc.), and genre writing activities (informational brochures and posters, PowerPoint presentations, etc.) (Tippett et al., 2008). Five teachers said they would be willing to participate in the verification study, and four of those teachers worked in the same school. To maximize the number of classroom observations while minimizing travel time, those four teachers were initially selected as participants. See Appendix D for a copy of the teacher consent form.

Ms. Arden, a Grade 6 generalist teacher, obtained her Bachelor of Education degree in elementary education (with distinction) in 2003. Prior to entering this post-degree program, she had received a Bachelor of Arts in Greek and Roman History. Ms. Arden had seven years of teaching experience; although this was her first full year teaching the Grade 6 curriculum, she had worked as a substitute (supply) teacher and had taught Grades 5, 7, and 8 for one year each. Ms. Arden was also a second language specialist working with English Language Learners (ELLs) and was responsible for related district-wide activities such as a potluck dinner for all ELLs and their families. Other commitments during the year included coordinating a Japanese school exchange, coaching sports teams, supervising the Drama Club, and participating on the school Literacy Committee. Ms. Arden described her level of science expertise as novice and said that it was rewarding to watch her students question, discover, learn, and apply new knowledge gained through science explorations. Ms. Arden had been a participant in the larger project since its inception, with the exception of a year's maternity leave.

Ms. Brown, a Grade 6 generalist teacher with five years of experience, received her Bachelor of Education degree in elementary education, and spent the next three years working as a substitute teacher. She then taught Grade 8 for one year and had just been assigned to teach Grade 6 at a new school when she joined the project for the final year of researcher-facilitated workshops. Other responsibilities during the year included coaching sports teams and supervising the Student Council. Ms. Brown described her level of science expertise as average, noting that while she did not consider herself to be an expert science teacher, she was not intimidated by the requirement to teach science.

Ms. Clark was a Grade 7 generalist teacher who obtained her Bachelor of Education in 2000 and a Master's degree in Education with a specialization in Language and Literacy in 2008. She had 10 years of experience, including seven years teaching Grade 7, one year teaching Grades 6/7, and two years teaching Grade 8 Social Studies, Language Arts and Home Economics and Grade 6 Home Economics. Ms. Clark was the head of the Physical Education department and traditionally took a lead role in coordinating student athletics at the school and in overseeing the student yearbook. She rated her level of science expertise as general, stating that there were definitely areas such as chemistry that could be taught better by someone with more expertise. Ms. Clark had participated in the larger project since its inception, acting as a lead teacher, and had been involved in the initial negotiations between the school and the university.

Ms. Davis was a Grade 7 generalist teacher who had a Bachelor of Education and a Master's degree in Education with a specialization in Science Literacy. She had 16 years of experience, including 7 years teaching Grade 7. For the past 6 years, she had worked with Grade 6 students who can read fluently but who have difficulty comprehending what they are reading. Ms. Davis's other commitments at the school included the literacy committee and the numeracy committee. She rated her level of science expertise as developed to a high degree, especially in the area of science literacy, believing that students need to think critically and to use text features to understand and gather information from nonfiction text. Ms. Davis had participated in the larger project since its start in the role of lead teacher and had also been involved in the initial negotiations between the school and the university.

All four teacher participants were part of the team of teacher advocates who created an instructional resource that arose out of experiences with the project. During the period of the dissertation research, all four teachers took lead roles in professional development workshops during which they presented the instructional resource and the literacy strategies to their colleagues.

All students of these four Grades 6 and 7 teachers were invited to participate in the study. Those students who returned a signed letter of consent that included the signature of a parent or guardian were accepted as participants. (See Appendix D for copies of the student and guardian consent forms.) All students in the four classes took part in all science activities, as they usually would, but only participating students were interviewed and work samples were collected only from participating students. Table 16 shows the distribution of participants among the four classes. The small number of participants in Grade 7 combined with teachers' conflicting schedules for science instruction resulted in my decision to focus on the Grade 6 classrooms, teachers, and students. The total number of participants was teachers ($N = 2$) and students ($N = 31$).

Table 16

Potential Student Participants

	Students		Student participants	
	n	%	*n*	%
Grade 6 (Ms. Arden)				
Boys	19	65.5	12	66.7
Girls	10	34.5	6	33.3
Total	29		18	
Grade 6 (Ms. Brown)				
Boys	19	65.5	8	61.5
Girls	10	34.5	5	38.5
Total	29		13	
Grade 7 (Ms. Clark)				
Boys	14	46.7	3	37.5
Girls	16	53.3	5	62.5
Total	30		8	
Grade 7 (Ms. Davis)				
Boys	14	46.7	2	40.0
Girls	16	53.3	3	60.0
Total	30		5	
Grade 6				
Boys	38	65.5	20	64.5
Girls	20	34.5	11	35.5
Total	58		31	
Grade 7				
Boys	28	46.7	5	38.5
Girls	32	53.3	8	61.5
Total	60		13	
All Four Classes				
Boys	66	55.9	25	56.8
Girls	52	44.1	19	43.2
Total	118		44	

Data Collection

Data were collected using both quantitative and qualitative techniques that involved reasonable time demands and reflected school and school district policy. Quantitative data sources included the School Wide Write (SWW), the District Assessment of Reading Task (DART), a teacher questionnaire, and the pre- and postassessment measures of representational competence. Qualitative data sources included classroom observations, student work samples, and semistructured interviews. Each of these sources is described in more detail in the following sections.

School Wide Write and District Assessment of Reading Task.

All students attending the school in which the study took place are required to complete reading and writing assessments during the fall and spring of each year. The SWW provides a snapshot of students' writing achievement, and the DART provides a similar snapshot of students' comprehension of expository texts. The fall SWW and DART assessments took place in early October 2009.

The SWW and DART results were used in the absence of a standardized measure to compare groups of participants with respect to reading and writing achievement. A standardized measure would provide more valid and reliable results; however, administering the test would have required a significant amount of instructional time. It is also likely that asking students to complete a standardized test as part of the research project would have resulted in fewer participants for the study. Another disadvantage of these two measures is that the students' work is marked by teachers who may or may not closely follow the designated rubrics. Although interrater reliability was not measured, it is likely to be lower than it would be in the case of a standardized measure. However, these two measures are used by all schools in the district although the manner in which the measures are implemented and the results are evaluated may vary slightly. In addition, students were expected to complete the SWW and the DART so no extra testing was required; and the school administrators agreed to provide me with the results. Because the verification study was situated within the larger community-based research project, the decision to use the SWW and DART results ultimately was based on the district's current acceptance of and reliance on those two measures.

For the fall SWW, students watched a short clip from the movie *Ice Age*, an animated film about a talking, prehistoric squirrel—a storyline likely to perpetuate a number of science misconceptions! After viewing the clip, students were asked to write a recount about what they had just seen. Teachers assessed students' writing using the *British Columbia Performance Standards* Quick Scale for Personal Writing (Ministry of Education, 2009). The SWW instructions, protocol, rubric, and supplementary materials created by the school's literacy team and distributed to teachers are located in Appendix E.

The DART, administered in the fall and spring of each year, is based on an informational text that includes photographs, maps, and diagrams. The Grade 6 fall text was titled Storm Chasers and contained information about storms and the people who pursue and document them. Students were asked to read the text silently, read portions of it aloud, and answer questions based on the written and visual information. Teachers marked the DART following rubrics and scored student results from 1 (not yet meeting expectations) to 4 (exceeding expectations). The Grade 6 fall DART protocol developed by the school-based literacy team is located in Appendix F, along with question sheets, rubrics, and the informational booklet.

Teacher questionnaire.

The Science Curriculum Implementation Questionnaire (SQIC, see Appendix G) was developed by Lewthwaite and Fisher (2005) as a method of identifying factors influencing science instruction at the school and classroom level. The SQIC is a 49-item questionnaire that provides information about the adequacy of resources, time, school beliefs about science, the availability of professional support, and teachers' perceptions of their ability to teach science, their pedagogical knowledge, and their attitude toward and interest in teaching science. SQIC was statistically validated based on responses from 293 teachers in 43 schools in New Zealand; internal consistency was determined by calculating Cronbach alpha, and discriminant validity was determined using interscale correlations. Subsequently, SCIQ has been used in schools in New Zealand and Canada; it has also been translated into French.

SQIC data are often compiled to reflect group attitudes toward and about science (Lewthwaite & Fisher, 2005). However, in the verification study, the data were used to compare individual differences between teachers, a use that is still within the scope of the questionnaire. SQIC was selected as the most appropriate measure of teacher perceptions of science instruction that was available.

Pre- and postassessments of representational competence.

In order to assess students' representational competence, I developed the pre- and postassessment measures shown in Appendix H. The passage topics were selected because they were not a focus of middle school science units as mandated by the provincial government (Ministry of Education, 2005, 2006b). Once I found a passage suitable for the preassessment measure, I searched for a second topic that could be represented by a similar diagram (see Figure 31 for an example of a labelled diagram). In each case, a cross-sectional diagram of five (Earth's atmosphere) or six (parts of the sun) layers accurately represented the majority of the information contained in the written passage.

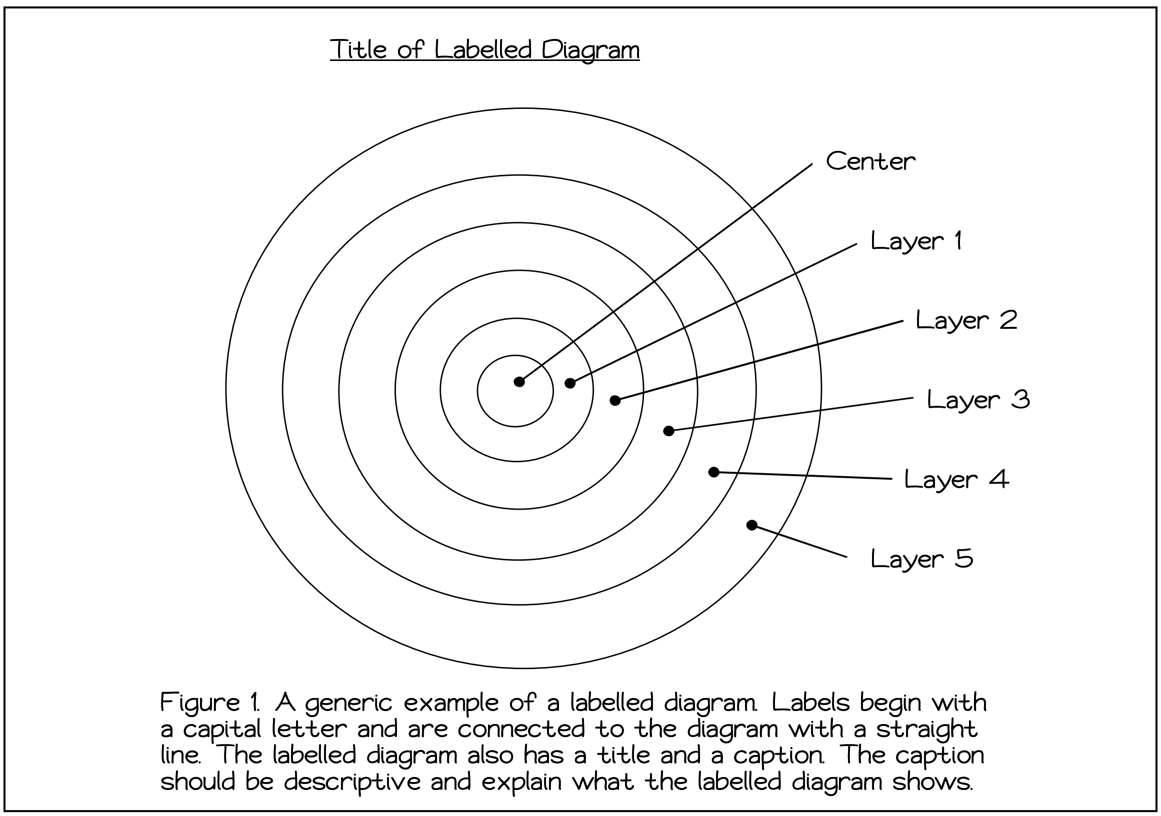


Figure 31. Example of a labelled diagram (cross-section) with title, labels, and caption.

The preassessment measure was based on a passage about the parts of the sun that was purportedly excerpted from a Grade 5 Macmillan/McGraw-Hill science textbook (http://www.monet.k12.ca.us/curriculum/librarylessons/Lessons /5th/5_How_to_Read_a_Diagram.pdf). I selected this passage because it was intended for a lower grade level than the students who would be participating in the study.

The postassessment passage about the Earth's atmosphere was designed to mirror the preassessment passage with respect to number of paragraphs and sentences. Although the readability levels (described in the following section) of the pre- and postassessment measures are not equivalent, I ensured that the postassessment had a higher readability level so that any positive changes in representational competence could not be attributed to readability differences in the two passages. The layout of the measures was identical; I used the same font, type size, and style for both measures; and I took care to position the paragraphs, the instructions, and the response space in exactly the same locations for each measure.

Readability calculations.

The readability levels of the pre- and postassessment passages were calculated to provide a means of comparing the passages rather than to predict the actual reading difficulty because readability formulae are mechanistic evaluations that do not account for the role of the reader in constructing meaning from text. The three methods chosen to provide a measure of comparison were Fry's Readability Graph (Fry, 2002), the Dale-Chall readability formula (Dale & Chall, 1948a, 1948b), and the Flesch-Kincaid readability calculations available in MS Word.

Fry's Readability Graph (Fry, 2002), shown in Figure 32, provides a grade-level readability based upon the number of syllables and the number of sentences contained in a 100-word excerpt. The process is supposed to be repeated for three excerpts selected at random. However, because the text passages used in the verification study were less than 300 words, I used the entire passage and calculated those values using the following equations:

$$\text{number of syllables in 100 words} = 100 \text{ X } \frac{\text{(number of syllables in passage)}}{\text{(number of words in passage)}}$$

$$\text{number of sentences in 100 words} = 100 \text{ X } \frac{\text{(number of sentences in passage)}}{\text{(number of words in passage)}}$$

For example, in the entire Parts of the Sun text, there are 397 syllables, 254 words, and 19 sentences. The number of syllables that would be in an equivalent passage of 100 words would be (100 X 397)/254 or 156 syllables. In the same manner, the number of sentences in an equivalent passage of 100 words would be (100 X 19)/254 or 7.5 sentences per 100 words. I then used these calculated values to obtain readability grade levels from the graph.

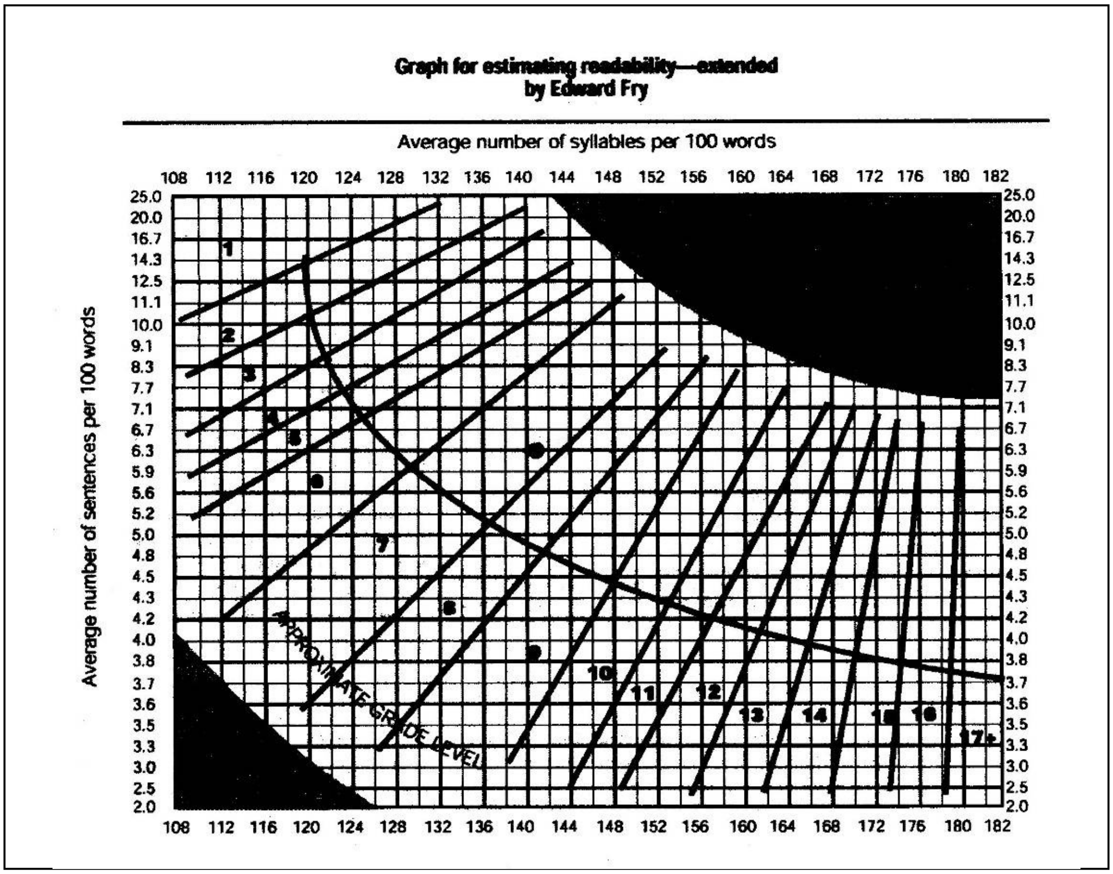


Figure 32. Fry's Readability Graph (Fry, 2002, p. 288).

The Dale-Chall formula is also based on excerpts of 100 words but uses average sentence length rather than number of sentences; therefore, I followed the steps shown in Table 18 without any adjustments other than selecting the entire passage rather than choosing excerpts. My justification for this decision was the same as my justification for calculating the 100-word equivalents for the use of Fry's Readability Graph (2002).

It might be argued that by calculating equivalent values for 100-word passages an element of error was introduced. However, I counter that the 100-word passages upon which the two methods are based are supposed to be selected at random from a more lengthy text passage, which also introduces the possibility of error in the resulting readability levels.

Table 17

Calculating Readability with the Dale-Chall Formula (Dale & Chall, 1948a, 1948b)

1. Select several excerpts of approximately 100 words.
2. Count the total number of words.
3. Count the number of sentences and calculate the average sentence length.
4. Count the number of words that are not on the Dale-Chall List of 3,000 Familiar Words, and calculate the percentage of unfamiliar words. This is the Dale score.
5. Reading grade score =

   (0.1579 X Dale score) + (0.0496 X average sentence length) + 3.6365

Readability statistics including word, sentence, and paragraph counts and the Flesch-Kincaid Grade Level score can be calculated on command in MS Word. The formula used is: (.39 x ASL) + (11.8 x ASW) – 15.59 where ASL = average sentence length and ASW = average number of syllables per word.

The results of all three methods of calculating readability are shown in Table 18. The readability levels are high, which can be attributed to the vocabulary load of each passage; each part of the sun or layer of the Earth's atmosphere has an unusual and multisyllabic name. High readability levels are common with science information text because of the amount of technical vocabulary and the frequent use of nominalization (Atkinson, Matusevich, & Huber, 2009; Fang, 2006). All four participating teachers previewed the assessment measures and rated them as challenging but manageable for the majority of their students.

These two representational competence assessment measures were developed especially for the verification study and were not piloted before use in the study. These measures, like the SWW and the DART, are not standardized. However, experts in science education and in measurement and statistics judged them to have face validity; the assessments appear to allow a measure of particular aspects of representational competence. Because the structure of the postassessment parallels the preassessment so closely, comparing the results should provide a snapshot indication of changes in particular aspects of representational competence, such as being able to select an appropriate form and knowing the names of the elements of a representation.

Table 18

Statistics on the Pre- and Postassessment Measures

	Assessment measure	
	Preassessment (Parts of the Sun)	Postassessment (Earth's Atmosphere)
Paragraphs	7	6
Sentences	19	20
Words	254	232
Syllables	397	403
	Readability	
Fry	Grade 9	Greater than Grade 17
Dale-Chall	9th to 10th Grade	11th to 12th Grade
Flesch-Kincaid	Grade 7.5	Grade 8.3

Classroom observations.

Classroom observations are labour-intensive and time-consuming; and if audio or video recordings are made, the subsequent transcription process is also time-consuming. However, observations can provide a comprehensive context, documenting student and teacher interactions. Observations can also be used to verify patterns that have been revealed through other methods of data collection and analysis. In the verification study, observations were used as sources of data in conjunction with quantitative assessment measures, semistructured student interviews, student artefacts, and teacher questionnaires.

Classroom observations may be made using checklists and rating scales that are based on either time or event sampling. Time sampling requires the observer to note target behaviours at specified intervals of time; in event sampling, all instances of the target behaviours are recorded. These types of observations are considered low-inference sources of data (Turner & Meyer, 2000). Observations may also be descriptive; in which case, field notes would be collected over time and would include detailed descriptions of general and target behaviours as well as contextual information. Field notes can be analyzed to reveal themes or a priori categories from theoretical frameworks may provide the analytical lens.

The field notes that I took were a combination of event sampling and descriptive observations. Because the lens for my observations was the exploratory framework that was proposed in Chapter 3, I documented whenever teachers referred to diagrams (and other visual representations) in the textbook as well as when teachers and students made use of diagrams during science (e.g., drawing on the board). These instances could potentially be linked to the semiotics or SFL dimensions of the exploratory framework proposed in Chapter 3. I also watched and listened for evidence of metacognitive strategies, such as teachers discussing how a particular strategy might be used. Finally, I made notes on teachers' actions, student groupings, and student activities; these notes were influenced by more formal constructivist-based observation protocols, such as the Reformed Teaching Observation Protocol (Arizona Collaborative for Excellence in Preparation of Teachers [ACEPT], 2000) and the Local Systemic Change Classroom Observation Protocol (Horizon Research Inc., 2003, 2005) described in the following sections.

Observation protocols.

The Reformed Teaching Observation Protocol (RTOP) was developed by a team at the ACEPT and was designed to allow trained observers to quantify the extent of reformed classroom teaching. Reform was characterized as a constructivist approach to teaching; and the results of reformed teaching would be a classroom community in which inquiry was emphasized, students would work together to negotiate meaning, and diversity would be respected (ACEPT, 2000). Other hallmarks of reformed teaching include the identification of preconceptions, the progression of lessons from concrete to abstract, and the expectation that students would reflect on their own work. RTOP is a criterion-referenced rating scale that consists of 25 items under the headings of lesson design and implementation, content (propositional and procedural knowledge), and classroom culture (communicative interactions and student/teacher relationships). Figure 33 contains an excerpt from RTOP.

		Never Occurred				Very Descriptive
1)	The instructional strategies and activities respected students' prior knowledge and the preconceptions inherent therein.	0	1	2	3	4
2)	The lesson was designed to engage students as members of a learning community.	0	1	2	3	4
3)	In this lesson, student exploration preceded formal presentation.	0	1	2	3	4
4)	This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.	0	1	2	3	4
5)	The focus and direction of the lesson was often determined by ideas originating with students.	0	1	2	3	4

Figure 33. Lesson Design and Implementation section of RTOP (ACEPT, 2000, p. 29).

A second classroom observation instrument, the Local Systemic Change Classroom Observation Protocol (LSC COP), was designed “to reflect the current standards for exemplary practice, but not to prescribe particular instructional strategies” (Horizon Research Inc., 2003, Notes on Use, para.1). The protocol emphasizes investigative and collaborative approaches to teaching and learning science. Other aspects include making connections to real-world situations, respect for diversity, and accommodation of student learning needs. LSC COP, a combination of checklists and rating scales, is intended to be used by trained observers, is suitable for observations of either science or mathematics lessons, and consists of the sections and subsections shown in Figure 34. Excerpts from LSC COP that contributed to my perspective during classroom observations are shown in Figures 35 and 36.

The purpose of classroom observations should inform the selection of more formal observation protocols or less formal anecdotal records (Flick, 2002; Hays, 2004). RTOP and LSC COP are formal observation instruments suitable for use in middle school classrooms, but both instruments are meant to be used by trained observers to reduce the subjectivity of the observations. Although I completed a graduate teaching internship in which these protocols were central, I could not be considered a trained RTOP or LSC COP observer; my purpose was to collect data about classroom science activities and interactions rather than to conduct a formal assessment of teaching. Therefore, I

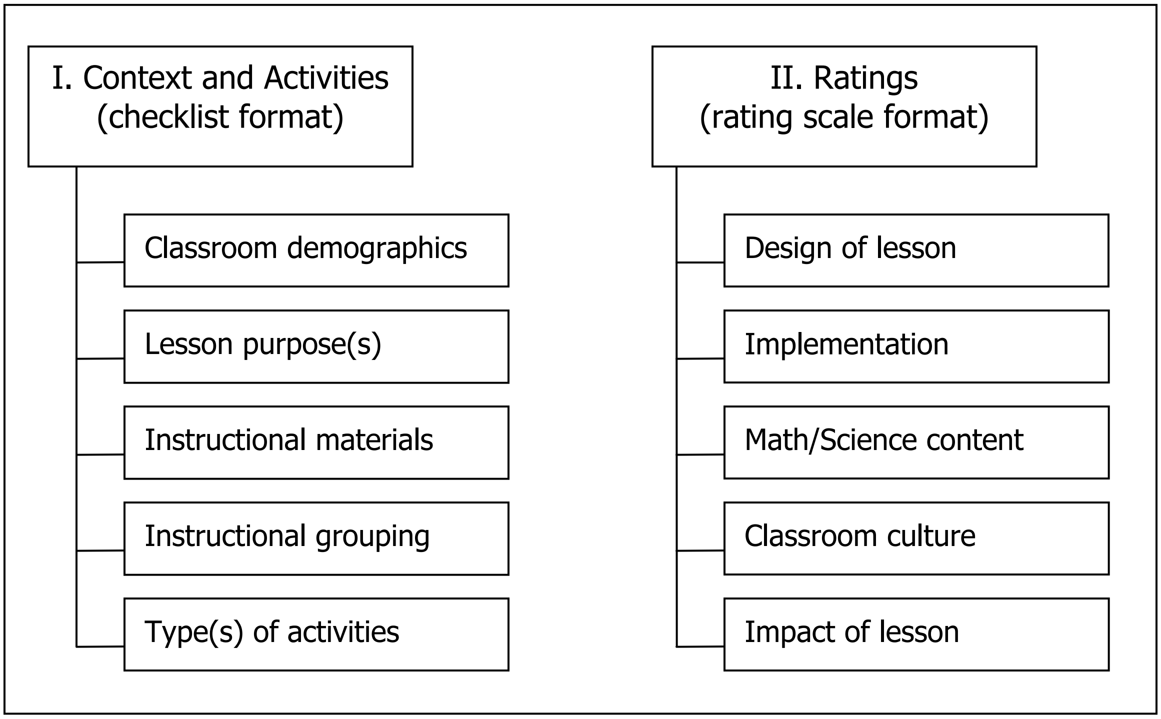


Figure 34. Components of the Local Systemic Change Classroom Observation Protocol (Horizon Research Inc., 2005).

B. Indicate the *primary intended purpose(s)* of this lesson or activity based on the pre- and/or post-observation interviews with the teacher.

☐ 1. Identifying prior student knowledge
☐ 2. Introducing new concepts
☐ 3. Developing conceptual understanding
☐ 4. Reviewing mathematics/science concepts
☐ 5. Developing problem-solving skills
☐ 6. Learning mathematics/science processes, algorithms, or procedures
☐ 7. Learning vocabulary/specific facts
☐ 8. Practicing computation for mastery
☐ 9. Developing appreciation for core ideas in mathematics/science
☐ 10. Developing students' awareness of contributions of scientists/mathematicians of diverse backgrounds
☐ 11. Assessing student understanding

Figure 35. Excerpt from the Lesson Purposes section of LSC COP (Horizon Research Inc., 2005, p. 3).

II. Implementation

A. Ratings of Key Indicators

	Not at all				To a great extent	Don't know	N/A
1. The instruction was consistent with the underlying approach of the instructional materials designated for use by the LSC.	1	2	3	4	5	6	7
2. The instructional strategies were consistent with investigative mathematics/science.	1	2	3	4	5	6	7
3. The teacher appeared confident in his/her ability to teach mathematics/science.	1	2	3	4	5	6	7
4. The teacher's classroom management style/strategies enhanced the quality of the lesson.	1	2	3	4	5	6	7
5. The pace of the lesson was appropriate for the developmental levels/needs of the students and the purposes of the lesson.	1	2	3	4	5	6	7

Figure 36. Excerpt from the Implementation section of LSC COP (Horizon Research Inc., 2005, p. 7).

decided to make anecdotal field notes rather than using the checklists and rating scales of the formal protocols. However, my anecdotal field notes were intended to capture specific aspects of constructivist teaching that were highlighted in the two protocols, such as identifying students' prior knowledge, developing a learning community, focusing on student ideas, introducing vocabulary, assessing understanding, and valuing of alternative modes of investigation or problem solving.

I began visiting the two Grade 6 classrooms in early September, and I was introduced to students as a researcher from the University of Victoria who was very interested in science. My role in the classrooms was as a participant observer; both teachers encouraged me to assist students during independent or small-group work. Students appeared to view me as one of several adults who were well known in their classrooms (teaching assistants, counsellors, and other support staff), albeit an adult who normally was only present during science. I took photographs of the classrooms and made notes on classroom décor. These contextual data were recorded whenever changes were made, for example, to the arrangement of desks or to student work displayed on the walls and bulletin boards.

When I was in the classroom, I took detailed field notes; on days when I was not present, teachers audio-recorded their science classes—an effort that I greatly appreciated. It should be noted that when transcribing the audio-recordings my focus was on the teachers' actions and statements. Student responses, if transcribed at all, remained anonymous even if the identity was obvious from the content of the recording. Similarly, field notes did not contain student names. This focus on the teachers rather than students meant that I did not need to consider whether students were participants or nonparticipants.

Student artefacts.

I collected, photographed, photocopied, or examined a range of student artefacts including science notebooks and completed projects such as Foldables, posters, and unit tests. Students' end-of-unit posters were discussed during semistructured interviews.

Student semistructured interviews.

All student participants were interviewed twice, the first time following the preassessment of representational competence and the second time following the postassessment. An interview guide, consisting of the questions shown in Table 19, was developed to provide a starting point for these brief interviews that typically lasted between five and eight minutes. Follow-up questions, framed to encourage participants to elaborate upon their answers, were based on individual responses to the initial question. The purpose of the interviews was to provide information about the decisions that students made when they were constructing their representations. The interviews were also meant to elicit students' knowledge about representational conventions, such as the names of the parts of a labelled diagram.

The semistructured interviews that were conducted during the verification study can be considered retrospective reporting (Ericsson & Simon, 1984) since they took place after students had completed their visual representations. The worksheets or posters were available for viewing during the interviews, so that students and I could point to specific aspects of the representations and that the artefact could serve as a reminder for students. Retrospective reports were chosen rather than think-alouds or concurrent reports because of the number of participants, the possibility of 'cross contamination' between sessions, the potential cognitive demands of think-alouds, and the level of familiarity needed with the think-aloud process. All students in a class read the text and constructed visual representations at the same time and then reported on their decisions and thought processes. If think-alouds were used, students would have had opportunities to talk about the assessment measure, which may have affected the decision-making processes of students who had not yet completed the assessment. In addition, think-alouds may increase cognitive load at the time of the task; training is usually required before a think-aloud protocol is followed, and the prompts must be worded so that responses will not interfere with the cognitive processes (Ericsson & Simon, 1984; van Gog, Kester, Nievelstein, Giesbers, & Paas, 2009). Using retrospective reports avoids an increase in cognitive load during an already cognitively demanding task.

Table 19
Student Semistructured Interview Questions

Part 1: Pre- and Postassessment

1. What was the first thing you thought when you were asked to read and visually represent?
2. Tell me about what you drew here.
3. Why did you decide to represent the information this way?
4. Do you know what this type of representation is called?
5. What is this part [point to caption, label, title, etc.] of your representation called?
6. If you were to do this activity again, is there anything you would add or change? Is anything missing from this representation?

There is a risk that information may be omitted in a retrospective report because participants might have had thoughts that occurred during the task that are not reported (Ericsson & Simon, 1984; van Gog et al., 2009). Information also might be constructed; participants might report having thoughts that did not actually occur during the task. However, data collected through verbal reports (think-alouds or retrospective reports) can provide more detailed information than can be obtained from simple pretest/posttest comparisons (Camp, 2003; Ericsson & Simon, 1984).

Timeline

Consent forms were distributed to all students in the two Grade 6 classes during the second week of September. Data collection for the dissertation project began in the third week of September 2009, as shown in Figure 37, and continued until February 2010. During the period of data collection, an introductory safety unit and a unit on diversity of life (one of three provincially mandated Grade 6 science units) were completed.

The pre- and postassessment pages, which were completed before and after the science unit, were given to students during a block deemed appropriate by each classroom teacher (e.g., Advisory, Science, or Language Arts). The classroom teachers gave no instructions to students other than “Read the following information and then visually represent that information in the box at the bottom.” Students who indicated that the page was too difficult for them to read independently had it read to them by an adult but received no other assistance.

During the first two weeks of October, all students in the school completed the SWW and DART as part of the school’s regular assessment program. The results of these two assessment measures were provided to me.

During classroom visits, I took detailed field notes, collected examples of worksheets, and took photographs of the classroom environment. I occasionally audio-recorded a lesson or a part of a lesson if an activity focused on the use of visual representations. I was not able to visit during every science block, due to some conflicts in the two teachers’ timetables and because of my own teaching commitments. Ms. Arden and Ms. Brown audio-recorded most of the blocks that I missed, and those audio-recordings were a rich source of data, supplementing my field notes.

I also examined students’ work when I was in the classroom, and I asked participating students for their permission to collect samples or to take photographs. Student artefacts included science notes, completed worksheets, and projects such as Foldables and posters. End-of-unit assessments included a traditional pencil-and-paper test and an informational poster. Those two items were collected for each of the participating students and were photocopied or photographed.

Event	Sept 21	Sept 28	Oct 5	Oct 12	Oct 19	Oct 26	Nov 2	Nov 9	Nov 16	Nov 23	Nov 30	Dec 7	Dec 14	Winter Break	Jan 4	Jan 11	Jan 18	Jan 25	Feb 1	Feb 8
Preassessment	★	★	★																	
SWW and DART			★	★																
Unit instruction [1]				←									→							
Classroom observations [2]	★	★	★	★	★	★	★	★	★	★	★	★	★		★	★	★	★		
Student Artefacts	★	★	★	★	★	★	★	★	★	★	★	★	★		★	★	★	★		
Unit assessment																★	★	★		
Postassessment																		★	★	★
Student interviews							★	★	★									★	★	★

[1] The unit on diversity of life began after a mini unit on science safety.

[2] Observations included field notes and audio-recordings.

Figure 37. Timeline for the dissertation research.

Methods of Data Analysis

Because the verification study generated quantitative and qualitative data, I selected appropriate methods for analyzing both types of data. The qualitative data, generated by interviews, observations, and audio-recordings, were coded and categorized. The quantitative data could often be displayed graphically, but I also carried out statistical analyses of selected data.

Qualitative Data: Coding, Categorizing, and Providing Context

The qualitative data analysis proceeded from the particular to the general as I searched for patterns. The qualitative data generated by student semistructured interviews were analyzed following an open-coding procedure (Flick, 2002). Interview responses were transcribed; and after an initial reading of the transcriptions, I reread the responses to specific questions and gave each response a descriptive label. I then developed response categories containing groups of similar labels. This process was iterative, as the use of a new label or the formation of a new category meant that previously viewed responses had to be re-analyzed with the new label or category in mind. My field notes and transcriptions were compiled, then coded and categorized in a similar process to reveal themes in classroom activities and teaching approaches. My interpretations of these two data sets were influenced by the exploratory framework described in Chapter 3 as I searched for examples and nonexamples for each dimension of the framework.

Visual data in the form of student-generated representations were analyzed using a rubric and teacher-developed criteria. These representations were also assessed according to Kozma and Russell’s (2005b) levels of representational competence.

My classroom observations included notes on aspects of the classroom environment, such as seating arrangements and bulletin board displays. Those notes were used to build a description of the classroom settings, providing a context for my interpretations and inferences.

Whenever it was appropriate, member checks (Denzin & Lincoln, 2000) were conducted so that participating teachers had an opportunity to verify my interpretations. Each teacher read her own biography and provided additional information to supplement the initial version of their professional education and experiences. The two Grade 6 teachers were asked to provide comments on the final themes and categories developed for each data set. Those comments were confirmatory in nature, resulting in no changes to my interpretations.

Quantitative Data: Statistical Analyses

Statistical analyses were conducted using MYSTAT 12 Version 12.02.00. MYSTAT is a free, student-oriented variation of SYSTAT 13 that is capable of statistical routines including probability calculations, random sampling, basic statistics, hypothesis testing, correlations, linear least squares regression, one-way frequency tables, stem-and-leaf plot, row statistics, fitting distributions, loglinear modelling, nonparametric tests, analysis of variance, and estimate modelling.

Quantitative data collected during the verification study included SWW and DART scores. Other sources of numerical data included frequencies of events noted during classroom observations and in transcripts of audio recordings. Statistical analyses in the verification study included descriptive statistics, such as standard deviation and variance, and Spearman's *rho* for examining the correlation of rank scores.

Summary

In this chapter, I provided an overview of the mixed-methods research approach and stated my rationale for designing a mixed-methods study. I described the participants in the verification study, outlined the qualitative and quantitative sources of data in the verification study, and provided a timeline showing the stages of data collection. I concluded the chapter with a brief description of the methods of data analysis that were used. In Chapter 6, I describe the analyses in more detail, present the results of the analyses, and discuss the inferences that I made based on those analyses.

Chapter 6
Data Analysis and Results

Data collection for this mixed-methods study yielded both qualitative and quantitative data. Sources of qualitative data included student artefacts, teacher-created worksheets, photographs, semistructured interviews, classroom observations, and audio-recordings of science lessons. The data from the interviews, observations, and audio-recordings were analyzed using a modified, open-coding procedure in which major themes were determined by the analytical lens; but subthemes were revealed through a process of labelling and categorizing, as described in Chapter 5 (Flick, 2002). The visual data in the form of artefacts, worksheets, and photographs were used to enrich the inferences and strengthen the claims that I constructed from the analysis of other data and help to address issues of subjectivity in observations. Sources of quantitative data included the pre- and postassessment measures, the SWW, and the DART. The data from these measures were analyzed statistically, using MYSTAT software (SYSTAT, 2007).

I begin this chapter by merging qualitative and quantitative data to construct a description of the two Grade 6 classrooms within which the dissertation research was conducted. I then describe the composition and characteristics of each class and provide an overview of the science units that Ms. Arden and Ms. Brown taught during the study. This contextual information is followed by an analysis of the representations that students created during the pre- and postassessments. Next, I describe themes that emerged from the quantitative analysis of the representations and the qualitative analysis of the semistructured interviews with student participants. Qualitative data from transcripts and field notes are then combined with quantitative data from the SQIC (Lewthwaite & Fisher, 2005) to illustrate the two teachers' approaches to teaching science. The chapter concludes with the themes that emerged from a modified, open-coding analysis of student interviews, audio-recordings, and classroom observations.

The Research Context

In this section, I describe the school at which I conducted the research, paying particular attention to the two classrooms in which the participants for the study were enrolled. I describe characteristics of the participating teachers, including years of experience and areas of expertise, and describe my overall impressions of the two classes. I also describe participant characteristics (e.g., reading and writing achievement) as indicated by snapshot measures.

The Classrooms

The research site was a school originally built in the 1940s, with additions made over the years. The two teachers whom I observed had classes in a wing constructed in the 1970s. Classroom walls were made of concrete blocks, the rooms were small, and storage space was limited. Each of the two classrooms had one small wall-mounted bookshelf, a free-standing storage cupboard, a sink situated in a detached double cupboard unit, two doors (one opening to the hallway and one opening to the playing fields), and two small windows. Florescent lighting was installed in a drop ceiling with acoustic panels. Each room had two computers for student use. Ms. Arden's room had an interactive whiteboard, a whiteboard, and a blackboard (see Figure 38); Ms. Brown's room had three blackboards (see Figure 39). There was little extra space for student movement or small-group work. However, students' desks were typically arranged in pairs or triads (Ms. Arden and Ms. Brown) or in pods of four or five students (Ms. Brown). This arrangement maximized opportunities for students to discuss ideas and concepts with one another despite limited space.

The Students

Ms. Arden's class consisted of 29 students (19 boys and 10 girls) and 6 of the students had IEPs. There was a full-time teaching assistant assigned to the classroom. Ms. Brown's class also consisted of 29 students, 19 boys and 10 girls, and 4 of the students had IEPs. Although there were several part-time assistants assigned to Ms. Brown's classroom (e.g., counselling support, Aboriginal student support, learning assistance support), due to scheduling issues, support personnel did not maintain a regular presence in the room. In addition, posting guidelines for the support positions, such as recruitment procedures and seniority, meant that a series of different teaching assistants worked in Ms. Brown's room during the year.

Figure 38. Ms. Arden’s classroom had a whiteboard, an interactive whiteboard, and a blackboard.

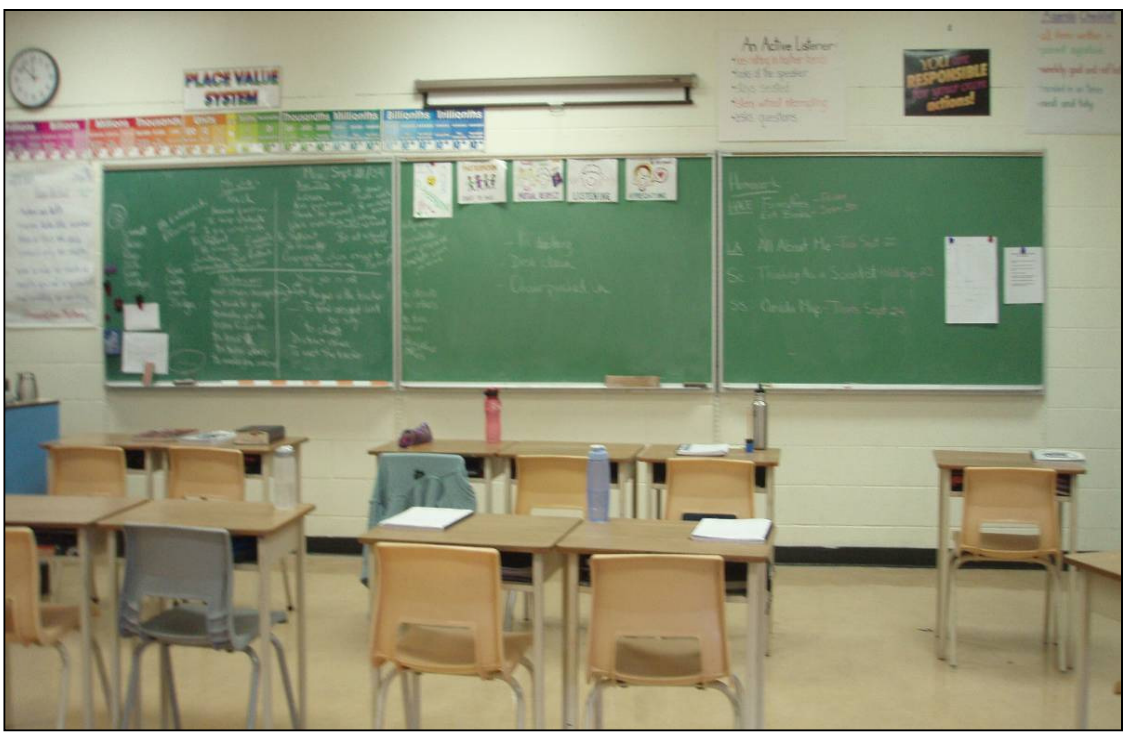


Figure 39. Ms. Brown’s classroom had three blackboards.

My observations in Ms. Arden's classroom indicated that there was a wide range of student abilities as well as a range of student interest and engagement in science. However, there were no obvious behaviour difficulties; typically, students were either on-task or off-task in a manner that was not disruptive to classmates. In Ms. Brown's classroom, the atmosphere was quite different. Although there was also an apparent range of student ability and expressed interest in science, there were frequent behavioural issues (e.g., particular students were often off-task in a disruptive manner and several student-student interactions were unproductive and disruptive) that made it difficult for Ms. Brown to maintain a calm, quiet atmosphere conducive to thoughtful science discussions.

SWW and DART scores.

As described in Chapter 5, the school at which the verification study was conducted utilizes data from SWW and DART as indicators of students' literacy proficiency, as do all elementary and middle schools in the school district. These two snapshot measures of student achievement are administered in the fall and spring of each school year. Therefore, the fall 2009 SWW and DART were used as benchmark measures in the absence of a standardized measure, such as the *Canadian Tests of Basic Skills*. SWW and DART scoring procedures and rubrics result in scores that range from 1.0 (not meeting grade-level expectations) to 4.0 (exceeding grade-level expectations). A score of 3.0 indicates that a student is fully meeting grade-level expectations. A score of 2.5 indicates that a student is meeting grade-level expectations in some but not all areas, and a score of 2.0 indicates that a student is minimally meeting grade-level expectations.

I used the results from these two measures to make some inferences about the participants in the context of the data available from the larger community-based project. First, to investigate the relationship between the two measures, I used MYSTAT software to calculate descriptive statistics and to calculate Spearman's *rho* correlation coefficient for the SWW and DART scores for all students in the school. The descriptive statistics and a scatterplot matrix of this correlation (Table J1 and Figure J1, respectively) are shown in Appendix J. There was a positive correlation between the two measures, $M_{SWW} = 2.27$, $M_{DART} = 2.31$, $rho = 0.58$, $n = 369$, $p < .05$. This relatively high nonparametric measure of statistical association between the two measures indicates that (a) students with higher SWW scores would likely have higher DART scores and (b) students with lower SWW scores would likely have lower DART scores.

Next, descriptive statistics (see Table J2) and Spearman's *rho* correlation coefficient for the Grade 6 participants' SWW and DART scores were calculated to see if similar results would be obtained. $M_{SWW(6)} = 2.22$, $M_{DART(6)} = 2.24$, and Spearman $rho = 0.64$; $n = 31$; $p < 0.05$ (see scatterplot matrix in Figure J2), indicating that with respect to these two measures the group of Grade 6 participants was similar to the larger population of all Grade 6, 7, and 8 students, and that increases in SWW scores were positively correlated with increases in DART scores.

Finally, the SWW and DART scores for the Grade 6 participants were analyzed by class to see if the two subgroups were similar. Descriptive statistics for the participants are organized by class in Table J3, and the corresponding scatterplot matrices are shown in Figure J3 in Appendix J. The correlation between the DART and SWW scores for the participants in Ms. Arden's class was $M_{SWW(Ms.\ A)} = 2.50$, $M_{DART(Ms.\ A)} = 2.53$, Spearman's $rho = 0.44$, $n = 18$, $p > 0.05$. The correlation between the DART and SWW scores for the participants in Ms. Brown's class was $M_{SWW(Ms.\ B)} = 1.85$, $M_{DART(Ms.\ B)} = 1.92$, Spearman's $rho = 0.71$, $n = 13$, $p > 0.05$. The correlations and the descriptive statistics indicated that the two subgroups were dissimilar and that the subgroups and the larger group of Grade 6 participants were also dissimilar.

However, the descriptive statistics do not provide a comprehensive picture of the two subgroups because the average score is not as informative as the number of students who attained each score. Table 20 and Figures 40 and 41 show the percent of participants scoring 1.0, 2.0, 2.5, 3.0, or 4.0 on the fall SWW (Figure 40) and on the fall DART (Figure 41), which permits a more comprehensive comparison of the two subgroups of Grade 6 participants and their achievement on these two snapshot measures. Note that SWW and DART produced rank scores rather than interval values, so the values along the X-axis are nonlinear.

The Grade 6 participants' performance on the SWW and DART was explored to determine if patterns suggested by the graphs in Figures 38 and 39 were significantly different. An independent *t*-test using separate variance (cf. Zimmerman & Zumbo, 2009) was conducted to compare the SWW scores for participants in Ms. Arden's class ($M =$

Table 20

Grade 6 Participants' Scores on the SWW and the DART

	Ms. Arden's students		Ms. Brown's students	
	n	%	*n*	%
		SWW		
1	2	11.1	4	30.8
2	4	22.2	5	38.5
2.5	5	27.8	4	30.8
3	7	38.9	0	0.0
4	0	0.0	0	0.0
Total	18	100.0	13	100.1*
		DART		
1	0	0.0	2	15.4
2	6	33.3	9	69.2
2.5	5	27.8	2	15.4
3	7	38.9	0	0.0
4	0	0.0	0	0.0
Total	18	100.0	13	100.0

*Total is greater than 100 because of rounding.

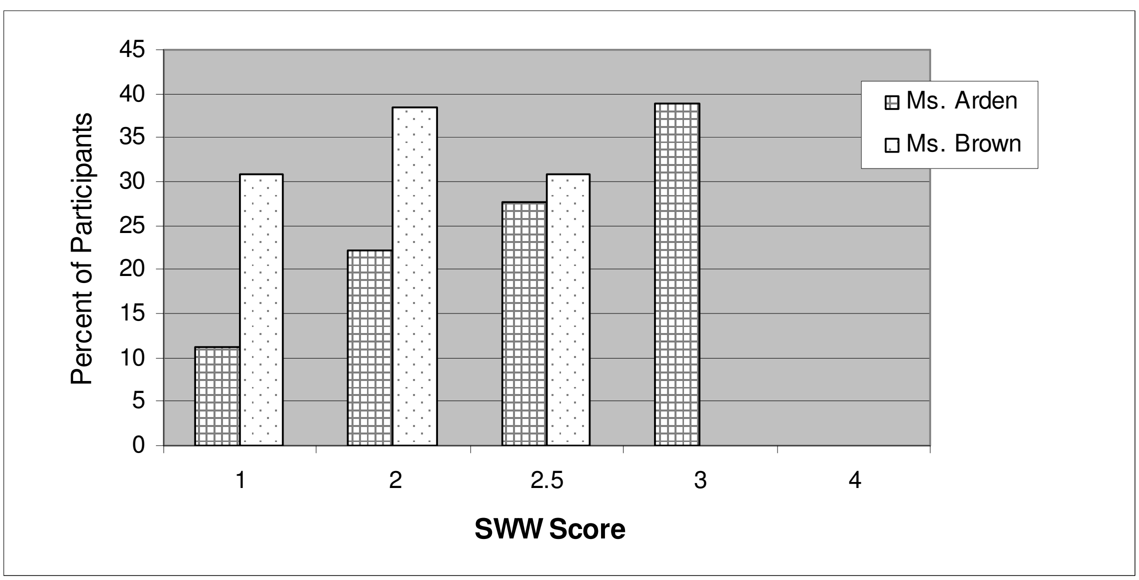


Figure 40. Fall SWW scores shown by percent of all Grade 6 participants.

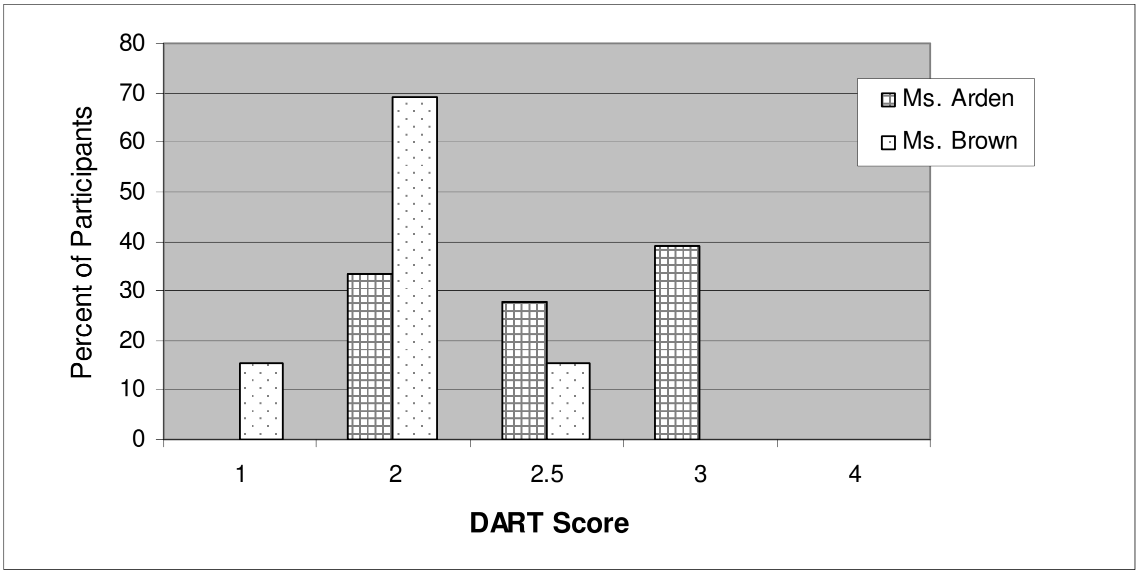


Figure 41. Fall DART scores shown by percent of all Grade 6 participants.

2.50, *SD* = 0.75) with the SWW scores for participants in Ms. Brown's class (*M* = 1.85, *SD* = 0.63). There was a significant difference, t (28.285) = 2.65, p = 0.013, which suggests that participants in the two classes had dissimilar scores on the SWW. An independent *t*-test using separate variance was conducted to compare the DART scores for participants in Ms. Arden's class (*M* = 2.53, *SD* = 0.44) with the DART scores for participants in Ms. Brown's class (*M* = 1.92, *SD* = 0.45). There was a significant difference, t (25.545) = 3.74, p = 0.001, suggesting that participants in the two classes had dissimilar scores on the DART.

The two Grade 6 classes were equivalent with respect to the total number of students and the ratio of boys to girls in each class. However, the two subgroups of participants were not equivalent, as indicated by the fall SWW and DART scores and by the number of participants in each class with IEPs. Additionally, the in-class support available for each class varied, with Ms. Arden's students having the same full-time teaching assistant in the classroom for the entire duration of the study and with Ms. Brown's students experiencing a series of part-time support personnel. These initial differences between the two Grade 6 classes led me to consider class/teacher as a possible variable throughout the remainder of the analysis.

The Science Curriculum

Classroom conditions (i.e., physical arrangement of the room, student characteristics, and presence of support personnel) provide only part of the context for the verification study. The science curriculum itself, including topics, resources, and activities, is another important aspect of the context. Ms. Arden and Ms. Brown agreed to teach science collaboratively by planning and implementing the same science units at the same time; as well, they chose to collaborate on planning activities, creating worksheets, and assigning projects. This collaboration meant that students in both classes would experience very similar curricula, albeit with differences in teachers' approach.

Ms. Arden and Ms. Brown decided to begin the year with an introduction to science, followed by a mini-unit on science safety, before commencing a unit on Diversity of Life, which is one of three mandated topics for Grade 6 (Ministry of Education, 2005). Both teachers incorporated an investigation of plant growth into the Diversity of Life unit although they took different approaches to these investigations.

Introduction to science.

The first week and a half of science instruction was centered on the question *What is Science?* Students in both classes watched and discussed demonstrations, such as poking a sharp pencil into a baggy full of water and adding mentos® to diet coke. Observations were recorded, and labelled drawings were introduced as powerful tools for conveying information.

Science safety mini-unit.

The mini-unit on science safety lasted approximately two weeks. Topics included following directions, acting responsibly, and being prepared. Activities included identifying safe and unsafe behaviours in a drawing and in a photograph of the students themselves watching a demonstration (see Figure K1 in Appendix K), selecting the most important safety rules and justifying the selection, and illustrating a safety rule for display in the classroom.

Diversity of Life unit.

Diversity of Life is one of three provincially mandated units for Grade 6 science. The key concepts and prescribed learning outcomes for this unit are shown in Figure 42. This figure clearly shows that aspects of disciplinary literacy, such as the importance of visual representations in science, are not emphasized in ministry documents. The textbook *BC Science Probe 6* (Nelson, 2005a) was the main resource for the unit; but teachers also incorporated supplemental resources, such as worksheets that were created to scaffold and structure activities or to help students record information. Several videos from the animated educational website BrainPOP (http://www.brainpop.com/) were shown during the unit because the school had a site membership and BrainPOP has a section about the diversity of life.

In conjunction with the Diversity of Life unit, Ms. Arden's class participated in Tomatosphere (2010), an educational science outreach project sponsored by Agriculture and Agri-Food Canada, the Canadian Space Agency, Heinz Canada Ltd, HeinzSeed, Ontario Centres of Excellence, Stokes Seeds, and the University of Guelph. The project has involved over 11,000 classrooms across Canada and the United States in planting, germinating, and observing the growth of plants from two sets of seeds. One set of seeds has been on a return flight to the International Space Station where they remained on board for approximately two months. The second set of seeds is the control group. Students compare the rate of germination between the two sets of seeds and report on the growth and development of the plants. The project has two major aims: to provide an opportunity for students to learn how to conduct a scientific experiment and to inspire students to pursue further education in the areas of science and technology. For approximately four weeks, students observed seeds planted in peat pellets and recorded the temperature and number of seeds germinating. Observations were recorded in tables, graphs, and labelled diagrams. The final project for this activity required students to represent their understanding of the Tomatosphere project and to communicate the results of the project to an audience of their peers.

Ms. Brown's students did not participate in the Tomatosphere project. However, once Ms. Brown had started the unit on diversity of life, her students conducted investigations into variables affecting the growth of bean seeds. The investigations were based on the three-page handout developed by Ms. Brown and shown in Figure K2 in Appendix K. Students were divided into groups, one for each of the three variables (water, light, temperature); and each group was divided into three smaller groups that would

GRADE 6 LIFE SCIENCE: DIVERSITY OF LIFE

Estimated Time: 25–30 hours
By the end of the grade, students will have observed and classified various organisms according to their form and function.

Diversity of Life
The study of the diversity of life is an introduction to micro-organisms and biological classification systems. Students use appropriate tools to observe plants, animals, and micro-organisms. Students also use classification systems to group organisms according to features of form and function.

Vocabulary
microscopes, slide, cover slip, magnify, micro-organism, species, kingdom, Plantae, Animalia, Monera, Protista, Fungi, invertebrate, vertebrate, mammals, birds, reptiles, amphibians, fish, classification systems, cell, cell membrane, nucleus, chloroplasts, chlorophyll, colouration, mimicry, camouflage, behaviour

Knowledge
- cells are the basic units of life and carry on all the functions needed for survival
- living things may be unicellular or multicellular
- plant cells differ from animal cells in their structure
- scientists classify organisms into groups according to internal and external features
- scientists traditionally use a five-kingdom system to classify organisms
- the kingdoms are: Animalia, Plantae, Protista, Monera, and Fungi
- each of the kingdoms has its own set of characteristics

Skills and Attitudes
- classify organisms using attributes
- demonstrate the use of a microscope to view a prepared slide
- demonstrate safe practices in investigations
- show respect for all living organisms
- use appropriate tools and techniques to gather, analyse, interpret, and share scientific ideas

Prescribed Learning Outcomes

Diversity of Life
- demonstrate the appropriate use of tools to examine living things that cannot be seen with the naked eye
- analyse how different organisms adapt to their environments
- distinguish between life forms as single or multi-celled organisms and belonging to one of five kingdoms: Plantae, Animalia, Monera, Protista, Fungi

Processes and Skills of Science
- manipulate and control a number of variables in an experiment
- apply solutions to a technical problem (e.g., malfunctioning electrical circuit)

Figure 42. Excerpts from *Science K to 7: Integrated Resource Package 2005* (Ministry of Education, 2005, pp. 38 & 106).

investigate a particular level of the variable (low, medium, high). Students brainstormed how they might investigate their assigned level of variable, using the handout to initiate discussions. Students made regular observations of their bean seeds/plants for approximately four weeks. The final assignment for the investigation was to complete the handout, which included drawing a labelled diagram.

Implementation of the Science Curriculum

The teacher plays an important role in the classroom context, and in this section I describe the two participating teachers and their approaches to teaching science. I also discuss the teachers' beliefs about science instruction as indicated by their responses on the SCIQ (Lewthwaite & Fisher, 2005). I used the field notes and transcriptions in combination with artefacts, such as handouts and photographs, to reconstruct the implementation of the science curriculum.

Observations and audio-recordings.

As part of the data collection during the verification study, I observed or recorded the teachers during science blocks over a 15-week period. Observations were made during 29 classroom visits, and 26 lessons were audio-recorded, resulting in field notes and transcriptions for a total of 55 science lessons; 28 lessons (9 visits and 19 recordings) for Ms. Arden and 27 lessons (20 visits and 7 recordings) for Ms. Brown, as shown in Figure 43. The difference in number of classroom observations for the two teachers was due to my teaching schedule; one of Ms. Arden's science blocks was scheduled at the same time as I was teaching at the local university. It should also be noted that not every science class was observed or audio-recorded because occasionally the participating teachers did not turn on their recorders. However, even if a conservative estimate of five blocks per teacher were missed, 85% of the science blocks were observed or recorded.

Although neither teacher used a particular lesson plan template or followed a specific lesson format, both teachers typically enacted three-part lessons with an introduction, a main event, and a postevent consolidation. They would introduce a lesson with a discussion, demonstration, or review of previous classes. The main event in the body of the lessons varied considerably and might include a guided inquiry activity, a step-by-step laboratory exploration, a textbook-based reading session, or a BrainPOP video. The postevent consolidation usually took the form of a class discussion. Both teachers appeared to take an interactive-constructive approach to teaching science (Yore, 2001), whether that approach was conscious or not. Rather than emphasizing whole-group

September 2009				
M	T	W	Th	F
	1	2	3	4
7	8	9	10	11
14 **Ms.B**	15	16	17 **Ms.A** **Ms.B**	18
21 **Ms.A** **Ms.B**	22	23 **Ms.A** **Ms.B (R)**	24 **Ms.A** **Ms.B**	25
28 Pro-D Day	29	30 **Ms.A (R)** **Ms.B**		

October 2009				
M	T	W	Th	F
			1 **Ms.B**	2
5 **Ms.A** **Ms.B**	6	7 **Ms.B**	8 **Ms.B**	9
12 Thanks-giving	13	14 **Ms.A**	15 **Ms.A (R)** **Ms.B**	16
19 **Ms.A (R)** **Ms.B (R)**	20 **Ms.A (R)**	21	22	23
26 **Ms.A (R)** **Ms.B (R)**	27 **Ms.A (R)**	28 **Ms.B (R)**	29 **Ms.A** **Ms.B**	30

November 2009				
M	T	W	Th	F
2 **Ms.A** **Ms.B**	3 **Ms.A (R)**	4 **Ms.B (R)**	5 **Ms.B** **Ms.B (R)**	6 **Ms.A (R)**
9 **Ms.A (R)** **Ms.B (R)**	10	11 Rem. Day	12 **Ms.A (R)**	13
16 **Ms.A (R)** **Ms.B**	17 **Ms.A (R)**	18	19 **Ms.A (R)** **Ms.B**	20
23 **Ms.A (R)** **Ms.B**	24	25	26 **Ms.A (R)** **Ms.B**	27 **Ms.A (R)**
30 **Ms.A (R)**				

December 2009				
M	T	W	Th	F
	1 **Ms.A (R)**	2	3 **Ms.B**	4
7	8	9	10 **Ms.B**	11
14 **Ms.A (R)**	15 **Ms.A**	16	17 **Ms.B**	18
21	22	23	24	25

Figure 43. Observations and audio-recordings (R) for Ms. Arden (Ms.A) and Ms. Brown (Ms.B) made between September and December 2009.

instruction, each teacher frequently had students work in pairs and small groups. Instead of following a reading/lecture format that front-end loaded direct instruction and that might not accommodate students' prior knowledge or provide opportunities for hands-on experience, each teacher tended to do most of their explicit teaching during the main event or consolidation stages of a lesson, on an as-needed and just-in-time basis.

To examine each teacher's approach to science instruction in more detail, I merged the typed field notes and the audio-recording transcriptions to form one large dataset, which I then analyzed to reveal specific types of events. The exploratory framework provided one lens for my analysis; I was seeking evidence of events that involved visual representations in general, labelled diagrams in particular, and the use of ICT to share visual representations with students. I anticipated that events emphasizing representations would highlight one or more of the proposed dimensions of cognition, metacognition, semiotics, or SFL, or perhaps reveal the need for additional dimensions. Key aspects of the two observation protocols described in Chapter 5—the *Lesson Design and Implementation* section of the RTOP (ACEPT, 2000) and the *Lesson Purposes* section of the LSC COP (Horizon Research, 2005)—also provided a lens for analysis; I sought evidence of events that could be considered as identifying students' prior knowledge, developing a learning community, focusing on student ideas, introducing vocabulary, assessing understanding, and valuing of alternative modes of investigation or problem solving. I anticipated that identifying these types of events would provide an indication of constructivist approaches to teaching.

Once these nine categories were selected as being representative of my research questions and of constructivist science teaching (the underlying theoretical frame for the study), I coded each separate activity, event, or episode. Each episode received only one code; therefore, in cases where an event could fit into several categories, the most appropriate code was selected. The same code could be given to more than one episode within a particular lesson but only if those episodes were separated by another episode type or if two completely different activities had the same code. Examples of each type of episode, activity, or event are provided in the following section.

Descriptive examples of episode types.

In this section, I describe two examples of activities that would receive a particular code for episode type. Although some of the examples refer to a specific teacher, in most cases both of the participating teachers implemented similar activities.

Teaching about Labelled Diagrams:

- Ms. Arden's students worked in pairs to compare two labelled diagrams. Based on the two examples, students developed a list of components that a labelled diagram should contain. The components included horizontally written labels that start with a capital letter and that are connected to the drawing with a line, a title, and a caption that explains what the diagram is about.

- Many of the teacher-created worksheets that accompanied the introduction to science, science safety, and diversity of life units contained labelled diagrams. Several of those worksheets are shown in Figures K3 to K6 in Appendix K.

Focusing on Students' Ideas:

- Ms. Brown's students were given a title page that consisted of four sections labelled: *A job that uses science*, *A skill that scientists use*, *Something I can explain using science*, and *A science discovery that helps us*. Students were asked to share their ideas for each section before beginning their own illustrations.
- During a popcorn reading session, where students took turns reading out loud and could 'jump in' whenever there is silence, Ms. Arden paused the reading frequently to allow students to ask questions and share information that was relevant to the topic of living things.

Assessing Understanding:

- Both teachers used rubrics to assess student work, and they often asked students to assess their own work using a rubric before handing in assignments. Examples of these rubrics are shown in Figures K7, K8, and K9 in Appendix K.
- Ms. Arden had a holistic rubric posted in her classroom, consisting of four different photographs of flowers. The photographs ranged from a black and white image of a single flower to a full color image of a bouquet of flowers complete with stems and leaves. She referred to this rubric when discussing expectations for competed work.

Building a Learning Community:

- Ms. Brown's students were working in small groups with each group completing a section of a worksheet based on the letters in the acronym THIEVES. Each small group then shared their answers with the whole class so that all students had the entire worksheet completed.
- Students were working on a page on science safety. They began by working on their own, then joined up with a partner, formed a larger group, and finally shared answers with the whole class.

Using ICT:

- Ms. Arden frequently used the interactive whiteboard as an alternative to an overhead projector. She also used it for activities that would be difficult to do in any other way, such as reviewing the diet coke and mentos demonstration using photographs and clip art.
- Ms. Arden's class played 20 questions against a computer program (e.g., http://www.20q.net/) with students taking turns to answer the computer's questions.

Valuing Problem-solving Alternatives:

- After Ms. Brown poked a sharp pencil into a plastic bag full of water, she asked her students to suggest ways in which the class might investigate why the bag did not leak. In subsequent lessons, Ms. Brown tried out some of the suggestions.
- Ms. Arden asked her students how to plan a demonstration to ensure that they are able to record results. She encouraged students to share and discuss their ideas and then incorporated her students' suggestions into the final procedure.

Identifying Students' Prior Knowledge:

- Both teachers used an anticipation guide as an introduction to a chapter in the science textbook. Students agreed or disagreed with a number of statements based on the information that was presented in the chapter. After reading, the anticipation guide was revisited so that students had the opportunity to compare their earlier understandings with what they now knew.
- Ms. Brown was introducing the topic characteristics of living things. She asked students to work with a partner to fill in a three-part Venn diagram for a plant, a fish, and a person. When these results were shared orally with the class, Ms. Brown found out what her students already knew about characteristics of living things.

Introducing Vocabulary:

- Ms. Brown's students were planning their investigation of variables affecting plant growth. Ms. Brown announced that students would be learning lots of new vocabulary, and students made a vocabulary Foldable that included words, definitions, pictures, and examples. The Foldables were added to throughout the activity as new words are encountered.

- Ms. Arden read the word ‘unicellular’ and asked, *What other words do you know that have* uni- *in them?* After several responses including unicorn and unicycle, Ms. Arden asked, *So, what do you think* uni- *means?* She repeated this approach when she came to the word ‘multicellular’.

Focusing on Visual Representations Other Than Diagrams:

- While discussing the letter V in the acronym THIEVES, students brainstormed a list of visuals that included pictures, videos, charts, graphs, cross-sections, maps, tables, labelled diagrams, and icons. Ms. Arden asked students to select three visuals from the textbook that they thought were important and to justify their selection.
- Ms. Brown’s students used sticky notes to record information about an animal and its adaptations. The notes were then placed on a world map according to habitat, creating a visual representation of animals around the world.

Results of the coding.

The results of my coding are shown in Table 21 and Figures 44 and 45. At least 85% of the lessons were coded; therefore, it is likely that the frequency of each type of episode is fairly representative of the overall instructional experience.

Coding revealed several differences in the number and types of episodes that occurred during science instruction in the two classrooms. Ms. Arden’s class experienced a much larger number of episodes than Ms. Brown’s class did, as shown in Table 21 and Figure 44, even though both classes were observed or recorded for a similar number of science lessons. Ms. Brown’s class was more challenging with respect to student behaviour (as noted in observational field notes) and student ability (as indicated by the snapshot measures of the SWW and DART). That level of challenge was reflected in a smaller number of distinct episodes. The pace of instruction in Ms. Brown’s class was slower with more students spending more time off task, which meant less time for revisiting, extending, or elaborating concepts. On the other hand, Ms. Arden’s students were more likely to be on-task; as a result, she spent less time explicitly managing behaviour and more time on activities that would reinforce or extend understanding. Both teachers, however, covered the Diversity of Life curriculum, providing learning opportunities that enabled students to meet or minimally meet the PLOs for the unit.

Table 21

Types of Episodes Occurring in Science Lessons during the Study

	Ms. Arden		Ms. Brown		Difference	
Focus of episode	*n*	%	*n*	%	*n*	%
Labelled diagrams	21	18.4	14	15.7	7	2.7
Students' ideas	16	14.0	17	19.1	-1	-5.1
Assessment	9	7.9	13	14.6	-4	-6.7
Learning community	16	14.0	13	14.6	3	-0.6
Information communication technologies	15	13.2	5	5.6	10	7.6
Valuing problem-solving alternatives	1	0.9	4	4.5	-3	-3.6
Students' prior knowledge	2	1.8	4	4.5	-2	-2.7
Vocabulary	8	7.0	10	11.2	-2	-4.2
Visual representations other than diagrams	26	22.8	9	10.1	15	12.7
Total	114	100	89	99.9		

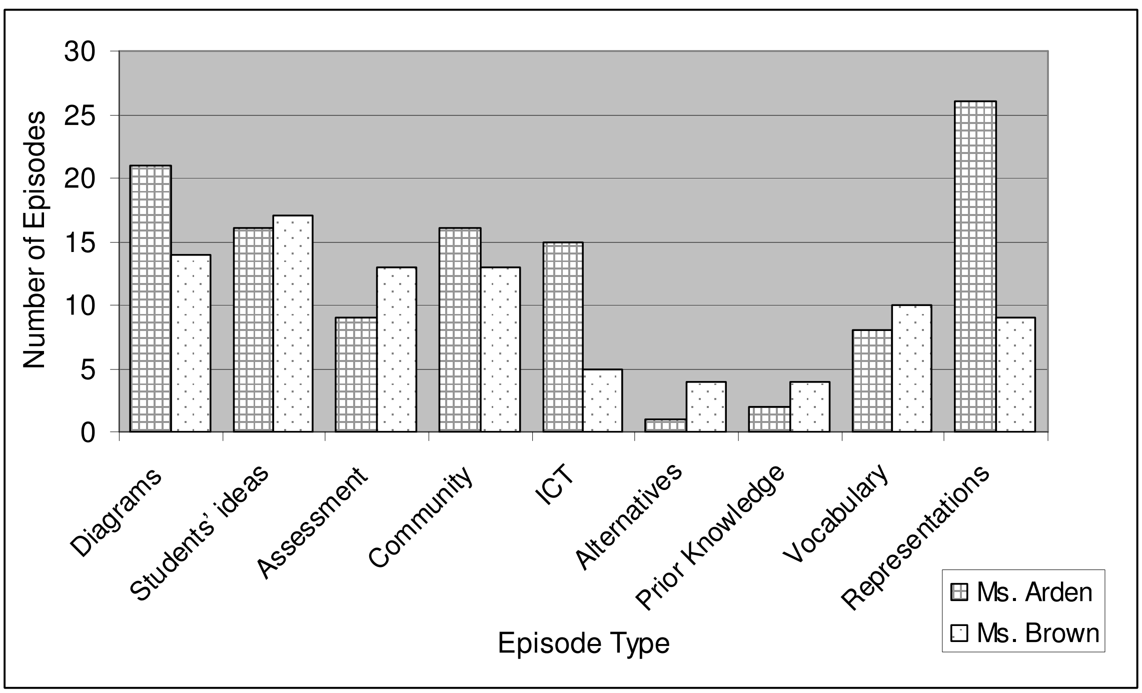


Figure 44. Number of episode types occurring during the verification study.

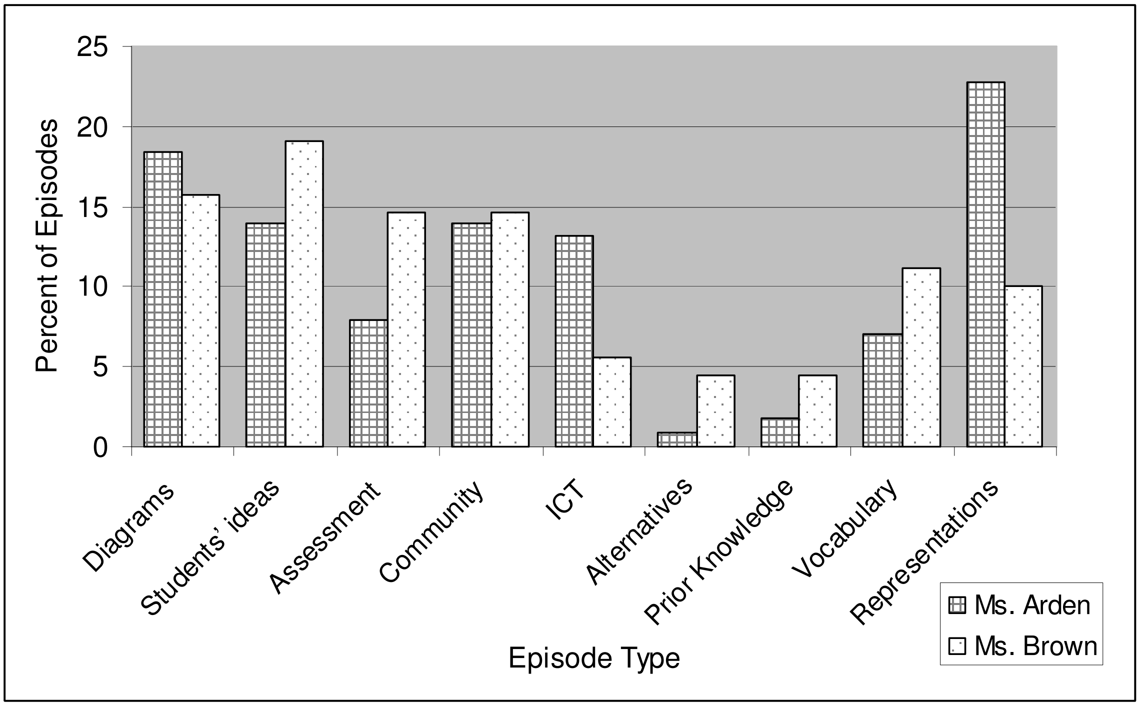


Figure 45. Percent of episode types occurring during the verification study.

Ms. Arden's class experienced a greater percentage of episodes that focused on labelled diagrams, the use of ICT, and visual representations other than labelled diagrams, as shown in Table 21 and Figure 45, indicating an overall emphasis on visual literacy in science. Ms. Brown's class experienced a greater percentage of episodes that focused on students' ideas, assessing understanding, valuing problem-solving alternatives, accessing students' prior knowledge, and vocabulary, indicating an overall emphasis on constructivist approaches to teaching science. It should be noted that both teachers could be considered to take an interactive-constructive approach to instruction (Yore, 2001) and both teachers incorporated aspects of visual literary in their instruction, so their overall emphases should not be used to label individual teaching approaches.

The differences in frequency of episodes are likely due to availability of resources, student differences (discussed previously), and teaching style. It is not surprising that Ms. Arden would emphasize the use of ICT more than Ms. Brown would—Ms. Arden had an interactive whiteboard in her classroom while Ms. Brown's classroom did not even have a whiteboard. The difference in emphasis on labelled diagrams and visual representations in general is most relevant to the verification study and will be discussed in more detail when the pre- and postassessments are analyzed. To examine the possible differences between teachers, the SCIQ (Lewthwaite & Fisher, 2005) was used to assess teacher beliefs about their science instruction in the context of their school.

Teachers' SCIQ results.

The SCIQ (Lewthwaite & Fisher, 2005) is a questionnaire consisting of 49 questions, with seven questions in each of seven areas: Professional Knowledge, Professional Attitude, Professional Adequacy, Professional Support, Resource Adequacy, School Ethos, and Time. Each response is scored from on a scale from 1 to 5, meaning that the total possible score for each area is 35. Ms. Arden and Ms. Brown completed the questionnaire at the end of the school year, rather than during the verification study. However, they were asked to think about the entire year when answering so that their responses would be more closely related to their beliefs about science in general than to any particular short-term event or influence.

The SCIQ scores for Ms. Arden and Ms. Brown were similar, as shown in Figure 46. Both teachers' responses resulted in high scores for their professional knowledge of, attitude about, and adequacy in science. These high scores were warranted, based on the quality of instruction that I observed in each classroom. Both teachers rated school ethos and support for science teaching as moderate, and my observations included no evidence to dispute those ratings. Both teachers' responses on the questionnaire resulted in time and resources receiving low scores. Ironically, Ms. Brown responded more positively about the availability of resources; Ms. Arden was somewhat less positive even though her classroom was equipped with a whiteboard and computer. The reason for this dissimilarity is not clear, and neither my classroom observations nor my conversations with the teachers revealed any insights. Ms. Brown's SCIQ responses indicated that lack of time was a major issue for her. Both teachers spent the same amount of time on science, but conversations with Ms. Brown revealed that she felt her instructional time was frequently reduced by the time she had to spend on classroom management. Ms. Brown noted that if she had more instructional time her students would have benefited from revisiting, extending, and elaborating ideas in science as well as other subject areas.

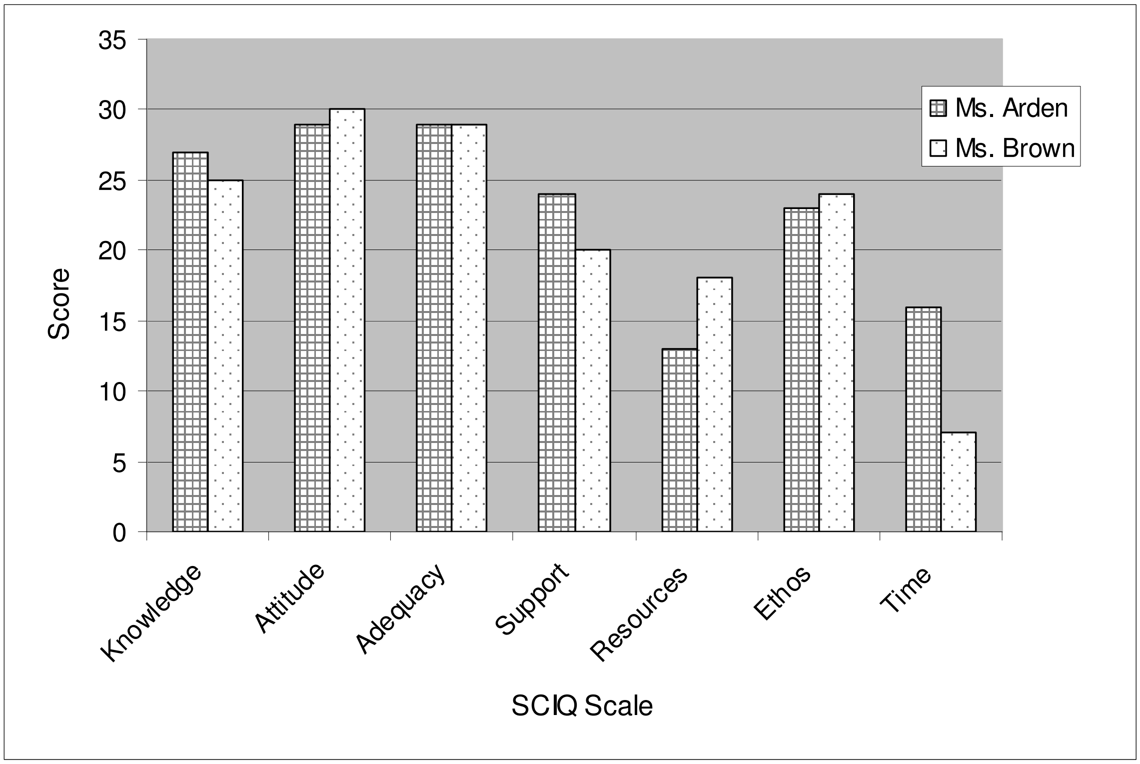


Figure 46. Ms. Arden's and Ms. Brown's scores on the SCIQ (Lewthwaite & Fisher, 2005).

Assessment of Students' Representational Competence

When communicating the results of classroom-based research, it is not sufficient to merely report pre- and postassessment results. A thorough description of the classroom, the curriculum, and the teacher help the reader to draw inferences about the research. The previous sections were intended to provide a context for the analysis that is detailed in the following sections.

Students were asked to read a passage about the Parts of the Sun (preassessment) or the Earth's Atmosphere (postassessment) and to visually represent the information contained in the passage. These two assessment measures were designed to provide an indication of students' ability to comprehend written information and then transform that information into a visual mode, with analysis of the resulting representations yielding information about aspects of participants' representational competence.

The transformation of information is a complex process that is likely to involve metacognition, knowledge of form and function, understanding of conventions, and domain knowledge, and those aspects were examined more fully through the semistructured interviews. The actual representations were assessed using a checklist (e.g., labels, title, diagram format) and were also given a holistic rating based on accuracy of information.

Assessment of Representations

To assess the student-generated representations, I created a preliminary checklist based on my predictions about the types of drawings or diagrams that students might produce. These predictions were based on my own knowledge of conventions from the established discourse community of science. I evaluated a random sample of six representations and then revised my preliminary checklist to accommodate unanticipated aspects, such as a participant's use of a pie chart. The revised checklist (see Appendix I) was then used to create a holistic rubric with rank scores ranging from 1 to 4, with an additional category for representations that accurately showed both layers and chemical composition. The holistic rubric, shown in Table 22, was reviewed by all four teachers, who reported that the rubric was appropriate for use with their students. This rubric could be used with participants of any age or level of expertise, because a score of 1 indicates a novice with a low level of representational competence and a score of 5 indicates an expert with a high level of representational competence. However, depending upon the level of expertise of a particular group, representations might be clustered within two or three of the ranks. A group of university science majors, for example, would likely score mostly 4s and 5s, while a group of primary students would likely score mostly 1s and 2s. Figures 47 through 52 are examples of the Grade 6 participants' visual representations for each of the rubric categories.

Table 22

Rubric for Parts of the Sun and the Earth's Atmosphere Visual Representations

Score	Description
1	No representation of information (picture rather than diagram or graph)
2	▪ Representation of information attempted ▪ Diagram of layers is highly inaccurate ▪ Format may be incorrect (e.g., circles to show %) ▪ Only chemical composition is represented
3	▪ Representation of information attempted ▪ Diagram clearly shows layers ▪ Some layers are missing +/or incorrectly labelled ▪ Representation of chemical composition may be attempted
4	▪ Accurate representation of information ▪ Diagram shows all layers ▪ All layers are correctly labelled ▪ Representation of chemical composition may be attempted
5	▪ Accurate representation of information ▪ Diagram shows all layers ▪ All layers are correctly labelled ▪ Accurate representation of chemical composition is included ▪ Color may be used

Figure 47. Rubric score = 1. No representation of information.

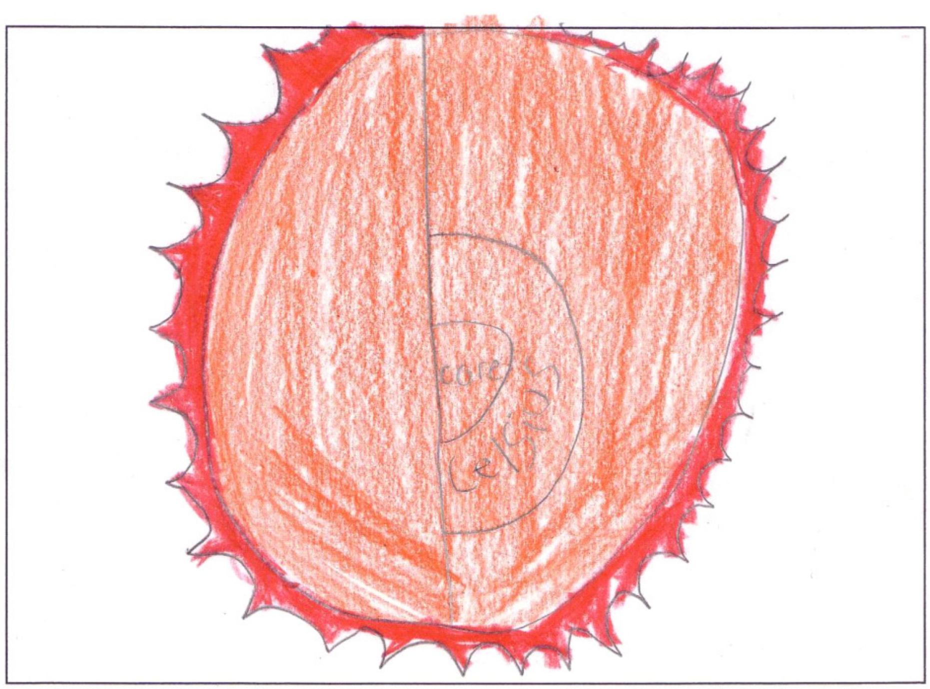


Figure 48. Rubric score = 2. Representation of information attempted; diagram of layers is highly inaccurate.

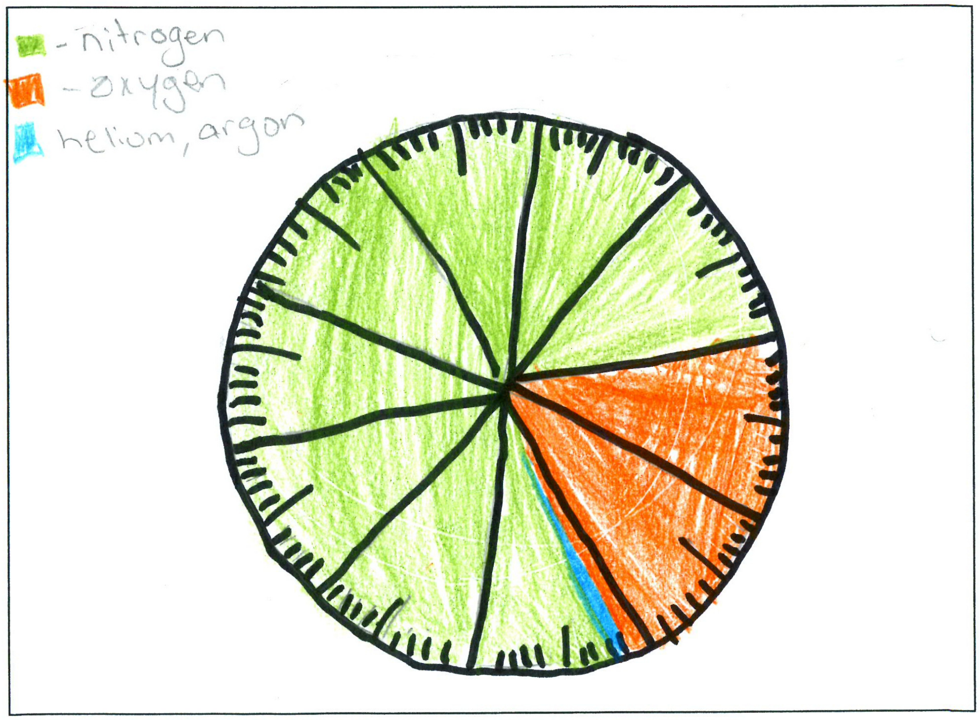


Figure 49. Rubric score = 2. Representation of information attempted; only chemical composition is represented.

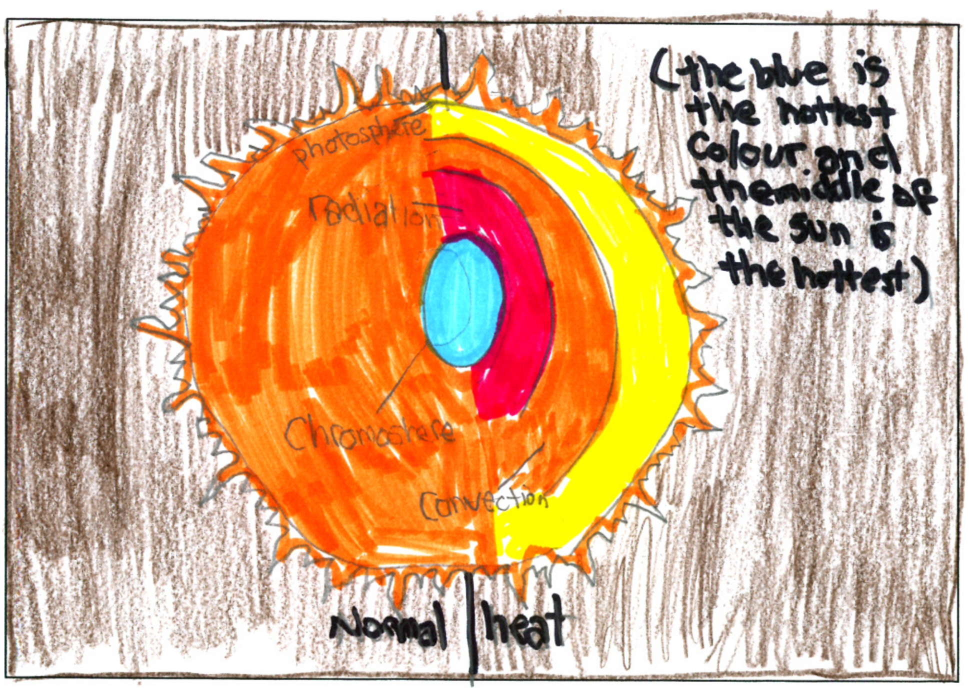


Figure 50. Rubric score = 3. Representation of information attempted; diagram clearly shows layers; some are missing +/or incorrectly labelled.

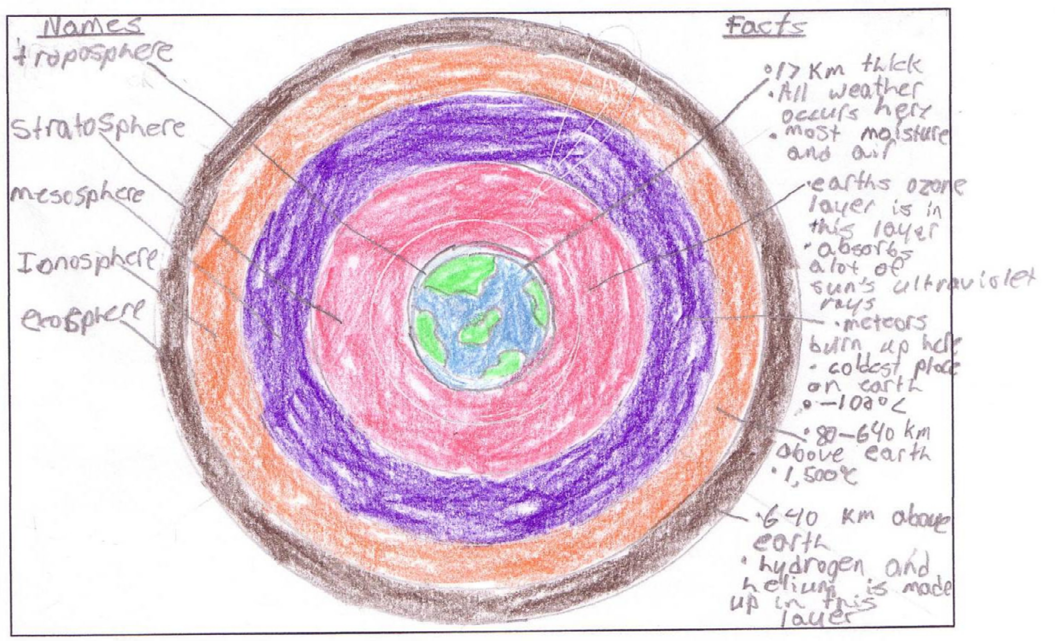


Figure 51. Rubric score = 4. Accurate representation of information; diagram shows all layers correctly labelled.

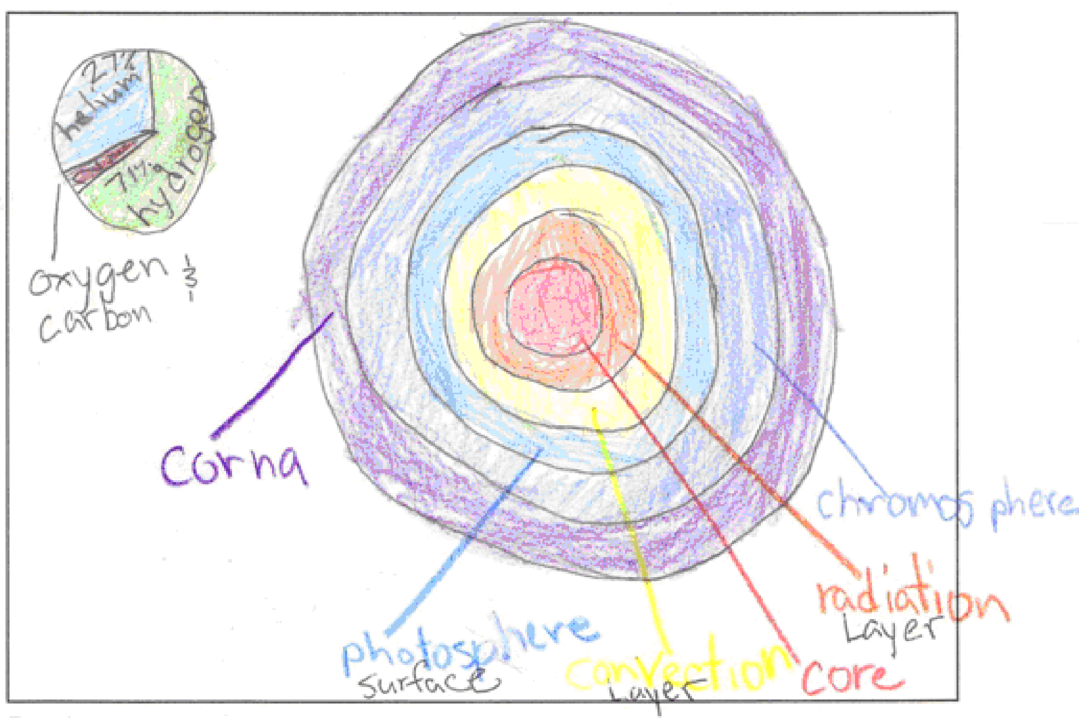


Figure 52. Rubric score = 5. Accurate representation of information; diagram shows all layers correctly labelled. Accurate representation of chemical composition.

Rubric scores for pre- and postassessment representations.

All rubric scores for the pre- and postassessments are shown in Appendix K. Table 23 summarizes the descriptive statistics for all Grade 6 participants, and Figure 53 shows the distribution of scores for all participants.

Table 23

Rubric Scores for Pre- and Postassessment Representations

	Pre (Parts of the Sun)			Post (Earth's Atmosphere)		
Rubric score	Ms. Arden *n* (%)	Ms. Brown *n* (%)	All *n* (%)	Ms. Arden *n* (%)	Ms. Brown *n* (%)	All *n* (%)
1	2 (11.1)	1 (8.3)	3 (10.0)	0	1 (8.3)	1 (3.3)
2	7 (38.9)	3 (25.0)	10 (33.3)	7 (38.9)	4 (33.3)	11 (36.7)
3	5 (27.8)	4 (33.3)	9 (30.0)	5 (27.8)	3 (25.0)	8 (26.7)
4	1 (5.6)	4 (33.3)	5 (16.7)	4 (22.2)	4 (33.3)	8 (26.7)
5	3 (16.7)	0	3 (10.0)	2 (11.1)	0	2 (6.7)
Total	18 (100)	12 (100)	30 (100)	18 (100)	12 (100)	30 (100)

Note. One participant did not complete the Parts of the Sun preassessment, and one participant did not complete the Earth's Atmosphere postassessment.

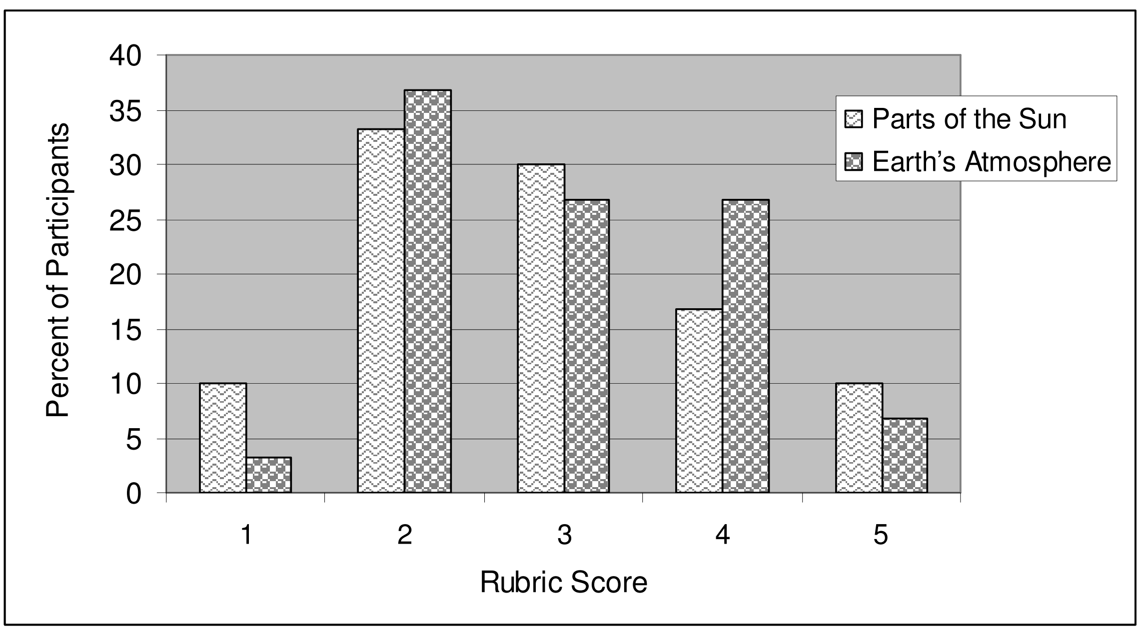


Figure 53. Rubric scores for the Parts of the Sun preassessment and the Earth's Atmosphere postassessment, by percent of participants.

The participants' pre- and postassessment representations appeared dissimilar when I was evaluating them with the rubric. However, a paired *t*-test calculated using MYSTAT software indicated that the average scores for all Grade 6 participants on the postassessment (M = 2.97, SD = 1.03) were not significantly different from the scores for all Grade 6 participants on the preassessment (M = 2.83, SD = 1.15); $t(28) = -0.20$, p = 0.846.

Reanalyzing results by participants' teacher, gender, and reading ability.

The results of the rubric scoring, shown in Table 23 and graphed in Figure 51 above, were dissimilar enough that further examination of the representations was warranted. I decided to reanalyze results according to the participants' teacher, gender, and DART score in order to investigate the possibility of instructor, gender, or reading comprehension effects. These three variables were selected because no further collection of data would be necessary. Data collection was restricted to the methods and measures outlined in the ethics approval; the school year had ended so no more data could be obtained. In addition, these three variables are widely noted in science education literature as having a role in science achievement (cf., Decoito, 2006; Fang & Schleppegrell, 2010; Gerstner & Bogner, 2009; Snow, 2010). Therefore, it was possible that participants' teacher, gender, and reading ability might be related to accuracy of visual representations of science information. I used the three variables to organize the data into various groups, as shown in Table 24. Although the means and standard deviations in rubric scores for particular groups do provide an indication of groups' similarity or dissimilarity, in the following sections I examine the rubric scores for each group in more detail.

Reanalyzing results by teacher.

The *t*-test results of preassessment scores indicated no significant differences between classes. Therefore, an ANOVA of postassessment scores appeared to be an appropriate statistic to explore the differences between classes, gender, and DART score. To explore the possibility of teacher or classroom differences in the rubric scores, I categorized the participants' rubric scores for the pre- and postassessments by teacher and graphed the results (Figures 54 and 55). It appears from these graphs that participants in Ms. Arden's

Table 24

Means and Standard Deviations in Rubric Scores for Three Variable Groups

		Preassessment (Sun)		Postassessment (Earth)	
Variable group	*n*	*M*	*SD*	*M*	*SD*
Teacher					
Ms. Arden	18	2.78	1.26	3.06	1.06
Ms. Brown	12	2.92	1.00	2.83	1.03
Gender					
Male	20	2.95	1.10	2.90	0.97
Female	10	2.60	1.27	3.10	1.20
DART score					
1.0	2/1*	2.50	2.12	3.00	
2.0	14/15**	2.50	0.76	2.67	0.98
2.5	7	3.43	1.27	3.57	0.98
3.0	7	3.00	1.41	3.00	1.16
4.0	-	-	-	-	-

Note. No students scored 4.0 on the fall DART. *One student was absent for the preassessment. **One student was absent for the postassessment.

class did less well on the Parts of the Sun preassessment than the participants in Ms. Brown's class. It also appears that the participants in Ms. Arden's class scored slightly higher on the Earth's Atmosphere postassessment. However, I used MYSTAT to calculate an ANOVA, which indicated that those apparent differences in representational competence were not significant, $F(1, 27) = 3.42$, $p = 0.075$. Realizing that the reliability of the statistical analysis was affected by the small numbers of participants (18 in Ms. Arden's class and 13 in Ms. Brown's class), I still wanted to examine the possibility of gender differences and to investigate correlations of representational competence with DART and SWW scores.

Reanalyzing results by gender.

To explore the possibility of gender differences in representational competence as indicated by the rubric scores, I categorized the participants' pre- and postassessment scores by gender and graphed the results (Figures 56 and 57). The graph in Figure 56 indicates that boys and girls attained similar scores on the Parts of the Sun

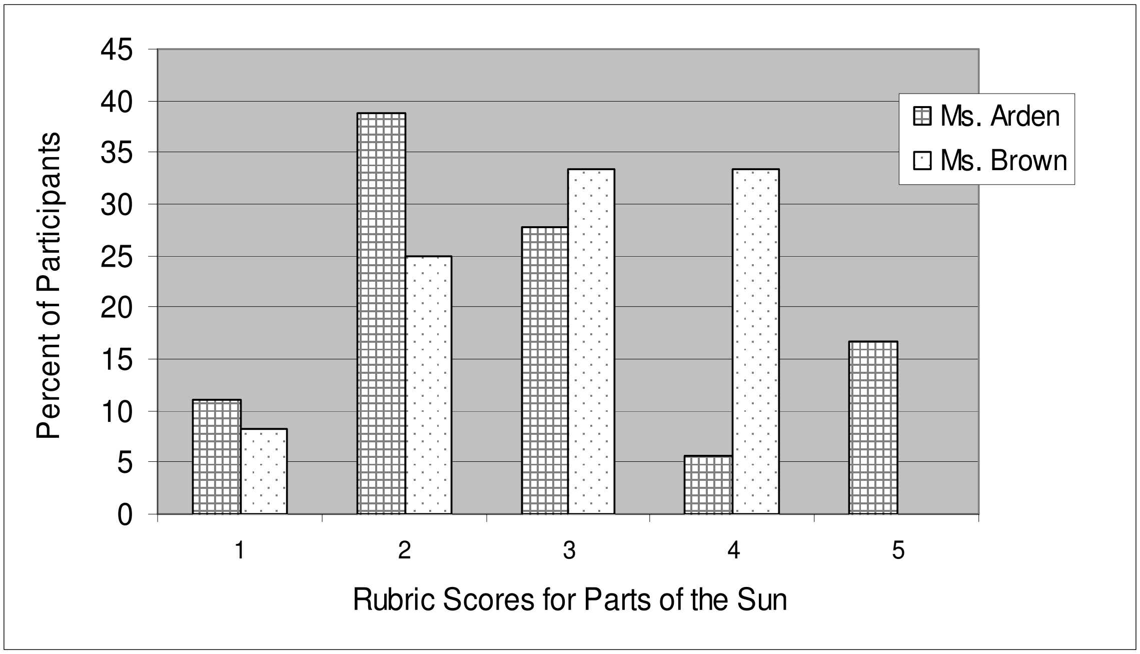


Figure 54. Rubric scores for representations of the Parts of the Sun preassessment, by percent of participants in each class.

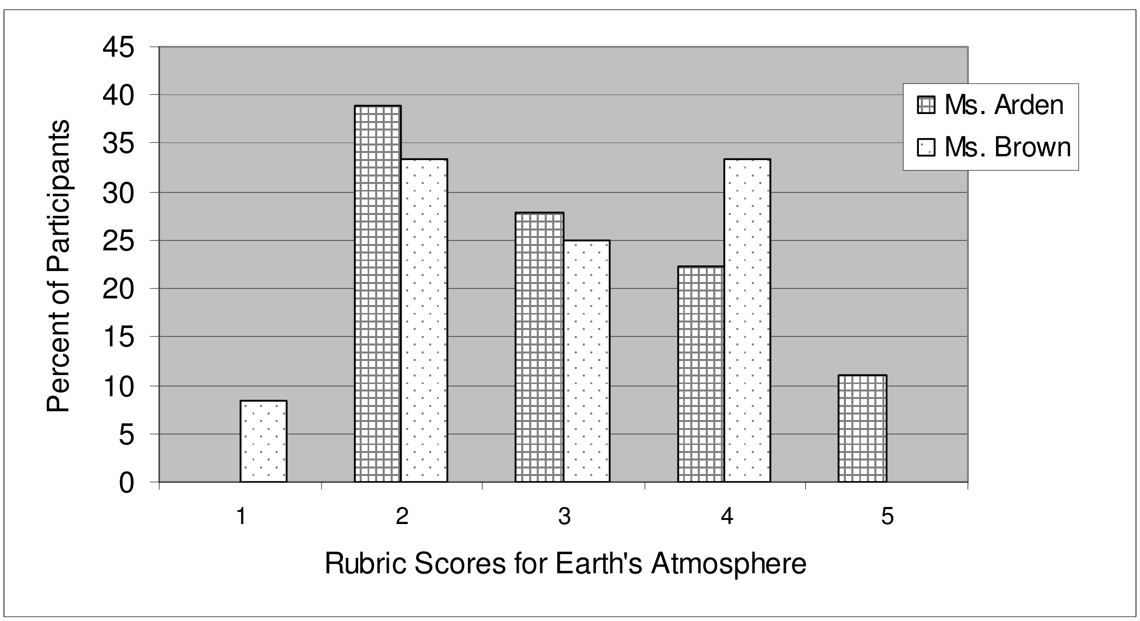


Figure 55. Rubric scores for representations of the Earth’s Atmosphere postassessment, by percent of participants in each class.

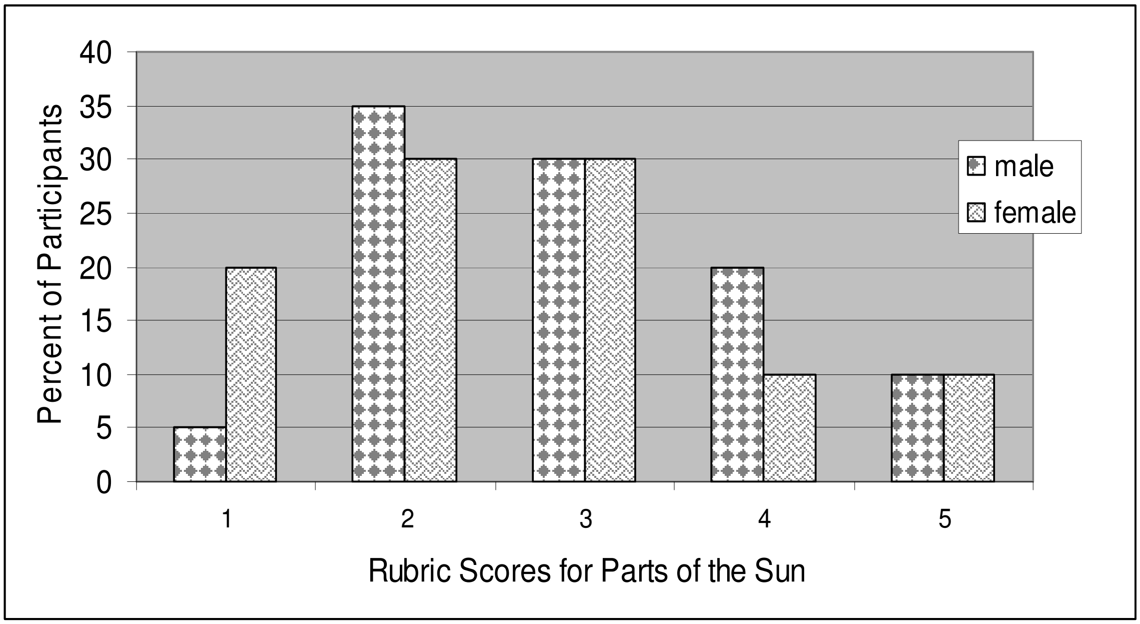


Figure 56. Rubric scores for Parts of the Sun preassessment representations, by gender of participants.

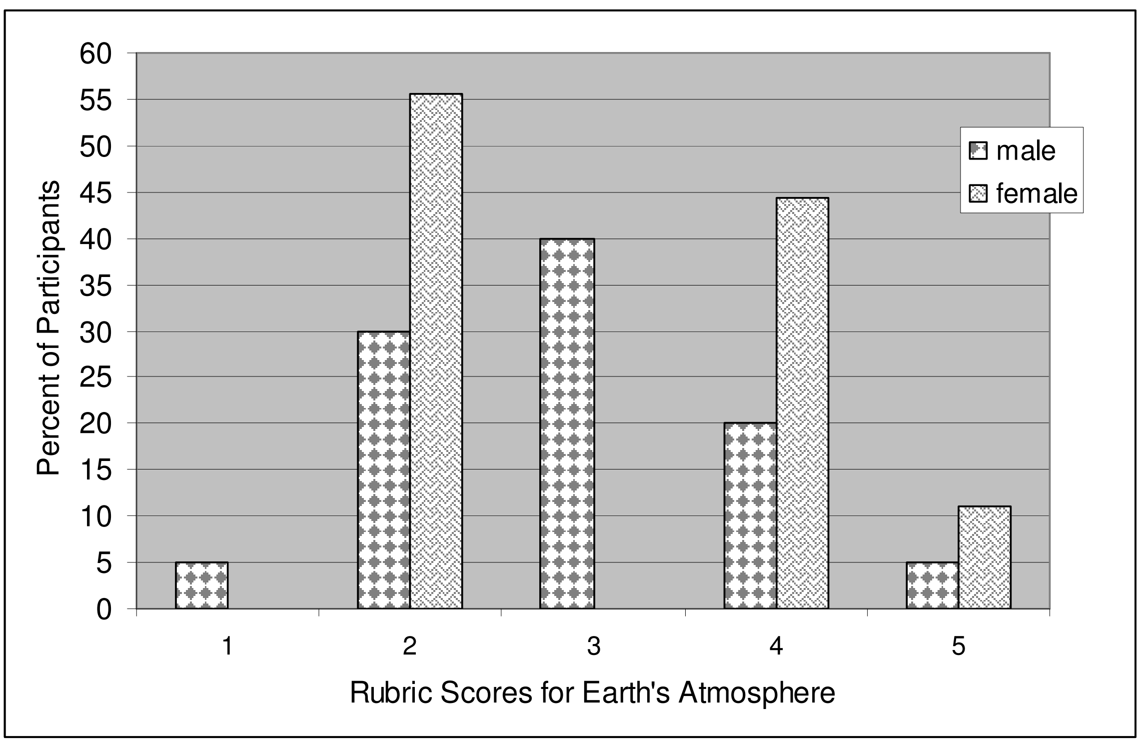


Figure 57. Rubric scores for the Earth's Atmosphere postassessment representations, by gender of participants.

preassessment. Although the graph in Figure 56 suggests a difference in the Earth's Atmosphere postassessment rubric scores, with girls scoring slightly higher, an ANOVA indicated that differences in representational competence between genders were not significant, $F(1, 27) = 0.51$, $p = 0.483$.

Reanalyzing results by DART scores.

To explore whether reading achievement (as measured by the DART) might be related to differences in the pre- and postassessment rubric scores, I categorized the participants' rubric scores by DART scores and graphed those results (Figures 58 and 59). There appears to be a pattern of participants with higher DART scores scoring higher on the pre- and postassessment measures of representational competence. Once again, however, the ANOVA indicated that any differences were not significant, $F(3, 25) = 0.41$, $p = 0.745$.

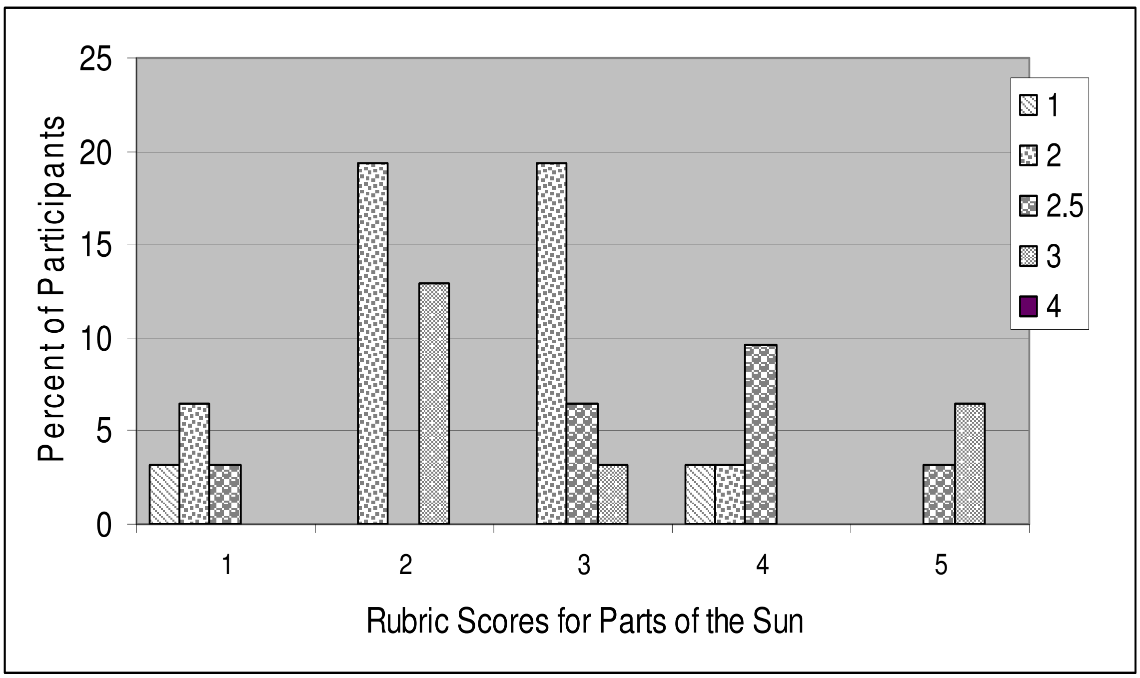


Figure 58. Rubric scores for representations of the Parts of the Sun preassessment, displayed by participants' DART scores.

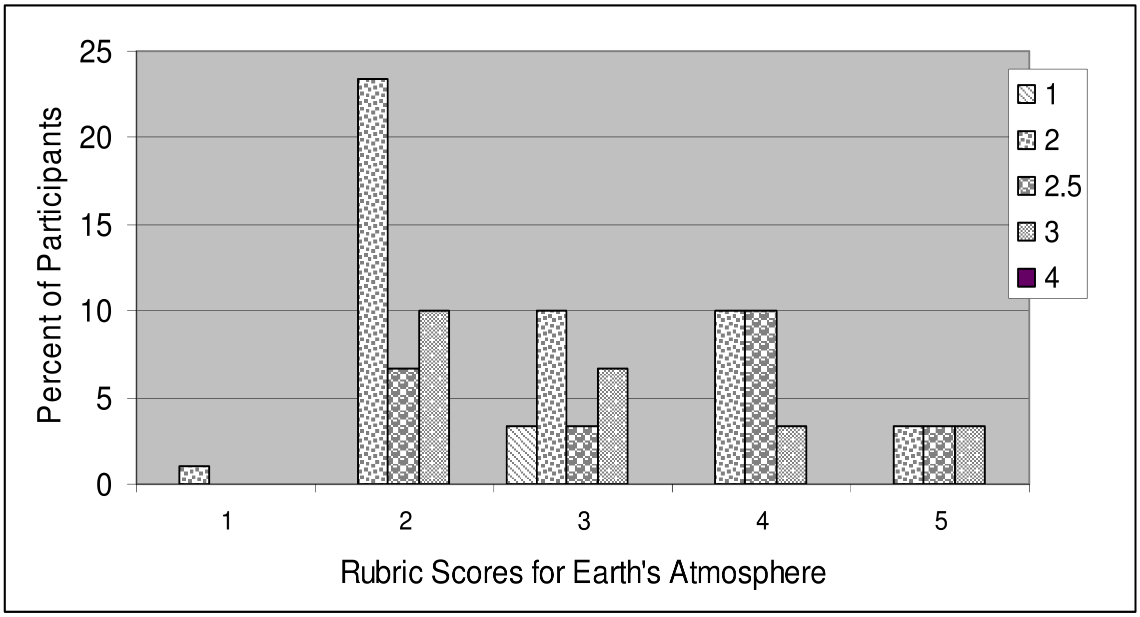


Figure 59. Rubric scores for representations of the Earth's Atmosphere postassessment, displayed by participants' DART scores.

Reassessment of representations.

The lack of statistical significance in any of the previous analyses led me to posit that perhaps my original rubric had been too general to capture small differences in quality between pre- and postassessment representations. I decided to evaluate the participants' representations more rigorously in an effort to reveal more subtle differences. I used three different methods of assessment: I counted the exact number of correct layers in the representation, I assessed the representations for the inclusion of particular components of a labelled diagram, and I rated the representations according to Kozma and Russell's (2005b) Levels of Representational Competence.

Number of correct layers.

The original rubric had three broad categories of none, some, or all layers correct; therefore, I reassessed the participants' representations by counting the exact number of layers that were correctly shown. I started with the core for the Parts of the Sun assessment and the Earth for the Earth's Atmosphere assessment because those parts were the first to be described in the written information. Each correct layer received 1 point with scoring stopping at the first incorrect layer. The results of this reassessment are shown in Table 25 and Figure 60.

Table 25

Number of Layers Correctly Identified in Pre- and Postassessment Representations

	Pre (Parts of the Sun)			Post (Earth's Atmosphere)		
No. correct	Ms. Arden *n* (%)	Ms. Brown *n* (%)	All *n* (%)	Ms. Arden *n* (%)	Ms. Brown *n* (%)	All *n* (%)
0	7 (38.9)	3 (25.0)	10 (33.3)	6 (33.3)	1 (8.3)	7 (23.3)
1	3 (16.7)	2 (16.7)	5 (16.7)	3 (16.7)	5 (41.7)	8 (26.7)
2	1 (5.6)	3 (25.0)	4 (13.3)	1 (5.6)	1 (8.3)	2 (6.7)
3	2 (11.1)	0	2 (6.7)	0	0	0
4	1 (5.6)	0	1 (3.3)	0	0	0
5	1 (5.6)	0	1 (3.3)	0	1 (8.3)	1 (3.3)
6	3 (16.7)	4 (33.3)	7 (23.3)	8 (26.7)	4 (33.3)	12 (40.0)
Total	18 (100)	12 (100)	30 (100)	18 (100)	12 (100)	30 (100)

Note. One participant did not complete the Parts of the Sun preassessment, and one participant did not complete the Earth's Atmosphere postassessment.

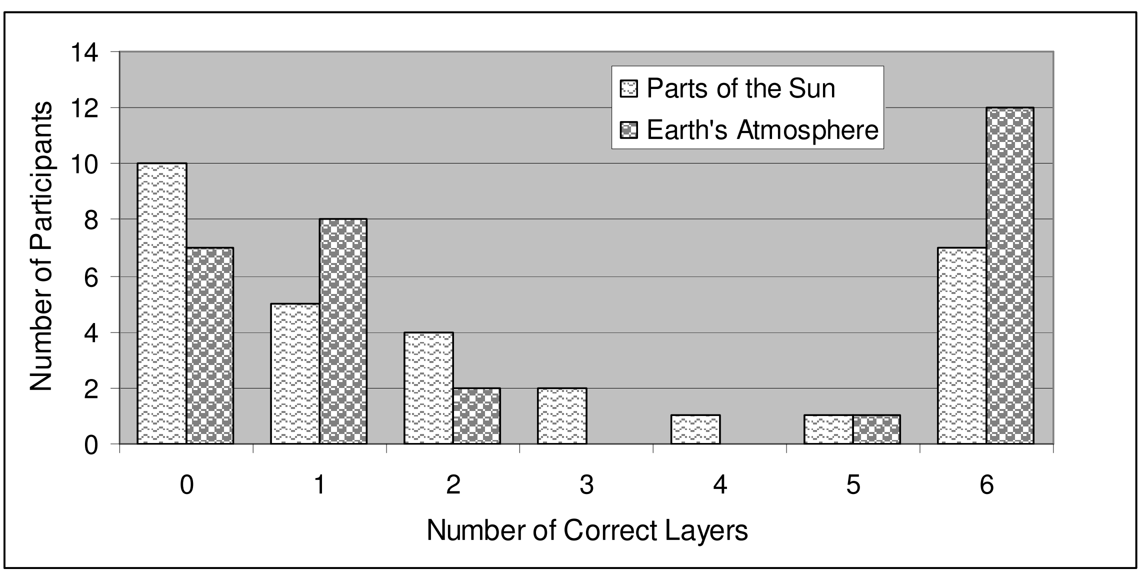


Figure 60. Number of correct layers in all Grade 6 participants' Parts of the Sun preassessment and Earth's Atmosphere postassessment.

A paired t-test indicated that the average number of correct layers on the postassessment ($M = 2.33$, $SD = 2.41$) were not significantly different from the scores on the preassessment ($M = 2.97$, $SD = 2.68$); $t(28) = -0.94$, $p = 0.356$. I decided to explore the number of correct layers more thoroughly, analyzing by participants' class, gender, and DART score, and following the same process that I used when analyzing the original rubric scores. Results of the ANOVA for class indicated no significant difference in the number of correct layers between classes, $F(1, 27) = 1.07$, $p = 0.311$. The ANOVA for gender indicated no significance, $F(1, 27) = 0.02$, $p = 0.883$. The ANOVA for DART scores also indicated no significant difference in the number of correct layers, $F(3, 25) = 1.67$, $p = 0.199$.

Criterion-based assessment of components.

In my second reassessment, I focused on the components of labelled diagrams that Ms. Arden and Ms. Brown had emphasized during science instruction. These components were used as criteria in a number of activities and projects during the period of the verification study and included title, caption, labels written horizontally and starting with a capital letter, and lines connecting the label to the drawing. One point each was scored for title, caption, labels, and lines; half a point was scored if labels began with a capital letter and half a point was scored if labels were written horizontally. It is important to remember that the teachers were introducing the concept of labelled diagrams and that not following these specific criteria is not necessarily incorrect within the discourse community of science. For example, some students chose to place labels within layers, a placement that is both informative and conventionally legitimate. However, the criteria for a labelled diagram were taught to students in both classes and, thus, provided a common point of reference. The results of my second reassessment are shown in Table 26.

A paired t-test indicated that the average scores on the Parts of the Sun preassessment ($M = 1.77$, $SD = 1.05$) and the Earth's Atmosphere postassessment ($M = 3.35$, $SD = 1.30$) were significantly different; $t(28) = -5.47$, $p < 0.001$. In addition, an ANOVA indicated that there was a significant difference in criterion-based scores between classes favouring Ms. Arden's class, $F(1, 27) = 21.68$, $p < 0.001$. There were no significant differences in criterion-based scores between genders, $F(1, 27) = 0.03$, $p = 0.875$. The ANOVA for DART scores indicated no significant differences, $F(3, 25) = 1.31$, $p = 0.294$.

Table 26

Criterion-based Scores for Elements of Pre- and Postassessment Representations

	Pre (Parts of the Sun)			Post (Earth's Atmosphere)		
C-B score	Ms. Arden *n* (%)	Ms. Brown *n* (%)	All *n* (%)	Ms. Arden *n* (%)	Ms. Brown *n* (%)	All *n* (%)
0	2 (11.1)	2 (16.7)	4 (13.3)	0	1 (8.3)	1 (3.3)
0.5	0	0	0	0	0	0
1.0	4 (22.2)	3 (25.0)	7 (23.3)	0	0	0
1.5	2 (11.1)	0	2 (6.7)	0	3 (25.0)	3 (10.0)
2.0	3 (16.7)	4 (33.3)	7 (23.3)	0	3 (25.0)	3 (10.0)
2.5	4 (22.2)	1 (8.3)	5 (16.7)	0	2 (16.7)	2 (6.7)
3.0	1 (5.6)	1 (8.3)	2 (6.7)	1 (5.6)	2 (16.7)	3 (10.0)
3.5	2 (11.1)	1 (8.3)	3 (10.0)	4 (22.2)	1 (8.3)	5 (16.7)
4.0	0	0	0	6 (33.3)	0	6 (20.0)
4.5	0	0	0	1 (5.6)	0	1 (3.3)
5.0	0	0	0	6 (33.3)	0	6 (20.0)
Total	18 (100)	12 (100)	30 (100)	18 (100)	12 (100)	30 (100)

C-B = criterion-based. *Note.* One participant did not complete the Parts of the Sun preassessment, and one participant did not complete the Earth's Atmosphere postassessment.

Levels of representational competence.

In my third reassessment, I rated each representation according to Kozma and Russell's (2005b) levels of representational competence. These levels of representational competence relate to the SFL dimension of the exploratory framework, which encompasses awareness of conventions as well as form and function. Note that the Parts of the Sun and Earth's Atmosphere representations can give only an indication of representational competence from Level 1 to Level 3 (Kozma & Russell, 2005b) since Levels 4 and 5 are based on using representations in problem solving and comparing, which were not examined within the scope of the study activities. The reassessment by level of representational competence affected only those representations that scored between 2 and 4 on my original rubric because the upper and lower limits of that rubric are fixed. The results of the third reassessment are shown in Table 27.

Table 27

Levels of Representational Competence Indicated by Pre- and Postassessment Representations

	Pre (Parts of the Sun)			Post (Earth's Atmosphere)		
LRC	Ms. Arden *n* (%)	Ms. Brown *n* (%)	All *n* (%)	Ms. Arden *n* (%)	Ms. Brown *n* (%)	All *n* (%)
1	3 (16.7)	1 (8.3)	4 (13.3)	0	1 (8.3)	1 (3.3)
2	12 (66.7)	8 (66.7)	20 (66.7)	2 (11.1)	10 (83.3)	12 (40.0)
3	3 (16.7)	3 (25.0)	6 (20.0)	16 (88.9)	1 (8.3)	17 (56.7)
Total	18 (100)	12 (100)	30 (100)	18 (100)	12 (100)	30 (100)

Note. LRC = Level of representational competence. One participant did not complete the Parts of the Sun preassessment, and one participant did not complete the Earth's Atmosphere postassessment.

A paired *t*-test indicated that the average level of representational competence indicated by the Parts of the Sun preassessment ($M = 2.07$, $SD = 0.58$) and the Earth's Atmosphere postassessment ($M = 2.53$, $SD = 0.57$) were significantly different, $t(28) = -3.28$, $p = 0.003$. In addition, an ANOVA indicated that there was a significant difference in levels of representational competence favouring Ms. Arden's class, $F(1, 27) = 41.74$, $p < 0.001$. There were no significant differences in levels of representational competence between genders, $F(1, 27) = 0.27$, $p = 0.608$. The ANOVA for DART scores indicated no significant differences in levels of representational competence, $F(3, 25) = 1.24$, $p = 0.318$.

Results of the assessment of representational competence.

This analysis of representational competence utilized four methods of assessing participants' representations and examined the possibility of class/teacher, gender, and reading comprehension affects. Significant differences were found between pre- and postassessment representations when those representations were evaluated according to the teachers' criteria for a labelled diagram. Significant differences were also found when representations were evaluated for levels of representational competence. There were no significant gender differences regardless of the method of evaluating the representations, and there were no significant differences that might be related to participants' reading comprehension ability. However, using the criterion-based evaluation and the assessment of level of representational competence, there were significant differences between the two classes.

The significant differences between the two groups of participants may be related to the differences in types and frequency of episodes during science instruction that were discussed earlier in this chapter. Ms. Arden's students experienced a greater number and percentage of episodes that focused on labelled diagrams specifically and on visual representation in general than Ms. Brown's students experienced (see Table 21 and Figures 44 and 45). Ms. Arden's students also experienced a greater number of episodes in total. The extra episodes were typically reinforcement and extension of the target concepts and ideas. Although the average episode in Ms. Arden's class was shorter in duration than the average episode in Ms. Brown's class, Ms. Brown appeared to spend more time on behaviour management within those episodes, meaning less instructional time overall for her students.

The significant differences between the two groups of participants may be related to differences in class composition. There were noticeable differences in student behaviour in the two classes, and a marked difference in the amount and consistency of learning support available to the two classes. These differences likely compounded the differences in the instructional context.

An informal conversation with Ms. Arden revealed some important information about the timing of the postassessments. Prior to completing the postassessment, her students received their marks for the end-of-unit poster assignment; as a class, they discussed aspects of the rubric (see Figure K9 in Appendix K), paying particular attention to the components of a labelled diagram. This discussion may explain some of the variation in results between the two classes. Although Ms. Brown's students had finished their posters, they were being evaluated when the postassessment was completed, which meant that Ms. Brown's students had not received feedback on the overall poster or on particular aspects such as the labelled diagram. Ms. Arden's feedback to her students can be considered just-in-time instruction about labelled diagrams, which means that participants in Ms. Arden's class were at an advantage in the postinstruction assessment.

Semistructured Interviews

The quantitative analysis of the participants' representational competence forms only a portion of the analysis of this mixed-methods study. Qualitative data that were collected through semistructured interviews were used to develop insights into participants' levels of representational competence and into their decision-making processes. In the following sections, I provide the number of participants who were interviewed after the pre- and postassessments. I describe the themes that emerged from a modified, open-coding of interview transcriptions and quote participants to give examples and nonexamples of particular aspects of each theme. Where appropriate, I include quantitative analyses to enhance the descriptions of the themes.

Participant and interview statistics.

The verification study included 31 Grade 6 participants. Ms. Arden had 29 students (19 boys and 10 girls) in her class, and 18 of those students (12 boys and 6 girls) signed and returned consent forms. After the preassessment, 13 participants (8 boys and 5 girls) were interviewed; after the postassessment, 16 participants (11 boys and 5 girls) were interviewed. One participant declined to be interviewed, and the other participants were absent during the interview sessions. Ms. Brown also had 29 students (19 boys and 10 girls) in her class. Consent forms were signed and returned by 13 students (8 boys and 5 girls). After both the pre-and postassessment, 10 participants (7 boys and 3 girls) were interviewed, and 3 participants declined to be interviewed. I conducted a total of 49 semistructured interviews with 27 participants, as shown in Table 28.

Previously, I compared the SWW and DART scores for the participants in each class and the larger group of Grade 6 participants. I could have compared the gender distribution of the group of participants with the larger group of Grade 6 students. However, the previous analyses indicated that there were no gender effects, so whether or not the gender distribution of the participants was equivalent to the gender distribution of the group of Grade 6 students as a whole is a moot point.

Themes Emerging from the Analysis of Representations and Interviews

The themes that are described in this section emerged from an analysis of the semistructured interview transcriptions and participants' representations. The exploratory

Table 28
Participants Interviewed after Pre- and Postassessments

	Interview			Interview	
Participant code	Pre	Post	Participant code	Pre	Post
A-4 M	☒	✓	B-1 M	✓	✓
A-5 M	✓	✓	B-4 M	✓	✓
A-6 F	✓	✓	B-5 M	✓	✓
A-7 F	✓	✓	B-6 F	✓	✓
A-8 M	✓	✓	B-16 F	☒	☒
A-9 F	☒	☒	B-17 M	✓	✓
A-10 M	✓	✓	B-19 F	✓	✓
A-11 M	✓		B-20 M	✓	✓
A-13 M	✓	✓	B-21 F	☒	☒
A-14 M	✓	✓	B-23 M	✓	✓
A-17 M	☒	✓	B-25 M	☒	☒
A-20 M	✓	✓	B-26 F	✓	✓
A-21 M	✓	✓	B-29 M	✓	✓
A-22 F	✓	✓			
A-23 M	☒	✓			
A-26 M	☒	✓			
A-27 F	✓	✓			
A-29 F	✓	✓			

Note. A = Ms. Adam's class, B = Ms. Brown's class, M = male, F = female, ✓= interviewed, ☒ = not interviewed.

framework informed my selection of themes because I was consciously seeking evidence of events that involved visual representations in general and labelled diagrams in particular. Evidence (both positive and negative examples) from both data sources was sought for themes that emerged from either data set. For example, the theme of 'color' emerged during my initial evaluation of the preassessment representations and was explored through questioning during the semistructured interviews. Although the guiding questions for the semistructured interview were developed before data collection began, the semistructured format meant that I could ask other probing questions as appropriate.

I made note of potential themes while I was evaluating the Parts of the Sun preassessment representations. Those potential themes included:

- participants’ use of color,
- participants’ choice of representational form,
- participants’ use of components of representations, and
- participants’ use of strategies to locate and select information to represent.

While I was transcribing the audio-recordings of the semistructured interviews, I continued adding to the list of potential themes. Typically, what I noted were variations or refinements of the original themes. For example, *locating and selecting information* became *planning for representing* and *selecting information* because many participants reported specific steps they took in the process of completing the assessment tasks.

As with my analysis of the observations and audio-recordings of the science lessons, my analysis of the semistructured interviews was influenced by the dimensions of the exploratory framework. Aspects of metacognition and awareness of form and function (SFL) were revealed through the questions that had been originally based upon the exploratory framework. Although I made a conscious effort to seek themes that emerged independent of that framework, ultimately the themes and categories that emerged from my analysis were all related in some way to the exploratory framework. If there had been themes or categories that did not connect to the exploratory framework, then I would have evidence to suggest a large-scale revision of the framework; instead, evidence suggested that the framework can be accepted as a starting point with refinements within the dimensions of the frame.

In the following sections, I describe the five themes and associated categories that were developed from my analysis of the participants’ representations and of the interview transcripts. The themes are: participants’ use of color, participants’ choice of representation (form and function), participants’ methods of planning for representing, participants’ knowledge of conventions, and participants’ selection of information to represent. The frequencies of themes and categories are presented along with examples of student responses for each category. Connections are made between the themes and the exploratory framework.

Verification Study Theme 1: Participants’ use of color.

The first theme I explored was participants’ use of color in their representations. Although students received no instructions about adding color, many participants used color, as shown in Table 29. I located all interview responses in which student participants mentioned the use of color. During both the pre- and postassessment interviews, 13 participants discussed their use of color. Open-coding analysis of these 26 interviews led to five main categories related to color: using up time, choosing colors, improving appearance, making information easier to read, and showing information. One student response, *colors didn't matter, I just labelled*, did not fit in any of these categories and was coded 'other'.

Table 29

Number of Participants Using Color in their Representations

	Pre (Parts of the Sun)		Post (Earth's Atmosphere)	
	B/W *n* (%)	Color *n* (%)	B/W *n* (%)	Color *n* (%)
Ms. Arden	6 (33.3)	12 (66.7)	8 (44.4)	10 (55.6)
Ms. Brown	5 (41.7)	7 (58.3)	10 (83.3)	2 (16.7)
Total	11 (36.7)	19 (65.3)	18 (60.0)	12 (40.0)

The categories and their frequencies are shown in Table 30, along with examples of participants' responses for each category. Note that the total number of instances is greater than the number of interviews because some responses received more than one label. For example, when asked why he had used color, one participant replied, *I had more time*. He also described how he had chosen colors: *It said … where is it … 'a red circle around the sun' and I wanted to show that that was the red circle.* These two statements were coded using up time and choosing colors respectively.

Participants' reasons for adding color to their representations may indicate more advanced levels of representational competence. More than 30% of the participants chose to add color so that the information they were communicating would be easier for others to understand. More than 40% of the participants used color to clarify information or to add more detail. Both of these reasons likely indicate metacognitive awareness as well as an awareness of the audience for the representation and provide support for the metacognitive and SFL dimensions of the exploratory framework.

Table 30

Participants' Reasons for Use of Color

Category	Instances N	% *	Examples of student responses
Using up time	3	11.5	▪ *I had extra time.* ▪ *I'd probably add color if I had time.*
Choosing colors	3	11.5	▪ *It usually tells you about the colors.* ▪ *The sun is reddish so I did that red.*
Improving appearance	5	19.2	▪ *I just kind of wanted to make it not look so plain.* ▪ *Just* [to] *make it look more interesting.*
Making information easier to read	9	34.6	▪ *I thought it would be easier to read.* ▪ *It was easier to see the parts.*
Showing information	11	42.3	▪ *Each ring has a different color so it's not all the same.* ▪ *To kind of like show more detail.*

Note. * % was calculated using the number of participants who mentioned color (26) rather than the total number of instances (31).

Verification Study Theme 2: Participants' choice of representation (form and function).

The second theme that emerged from my analysis of the pre- and postassessment representations was the form of the representation. During my initial evaluation of the Parts of the Sun representations, I discovered that almost all participants attempted to show information in a discipline-specific way, using a labelled diagram or a pie graph. A cross-section appeared to be the most common type of diagram; a small number of participants drew more complex cut-away diagrams to show both surface and subsurface features. I decided to explore the participants' choices quantitatively and qualitatively.

I initially sorted students' pre- and postassessment representations into three categories: pictures, cross-sections, and pie charts. I soon noticed that a few students had drawn both a pie chart and a cross-section and that some students had even combined the two types of representations into a more complex, yet parsimonious, representation of information (see Figure 61). I decided to re-sort the representations into six categories:

- picture, with no obvious attempt to represent information

- pie chart, with chemical composition shown
- cross-section, with some indication of layers; includes cut-aways
- separate cross-section/cut-away and pie chart (as shown in Figure 52)
- combined cross-section/cut-away and pie chart (as shown in Figure 61)
- other, with an obvious attempt to represent information (e.g., bar graph)

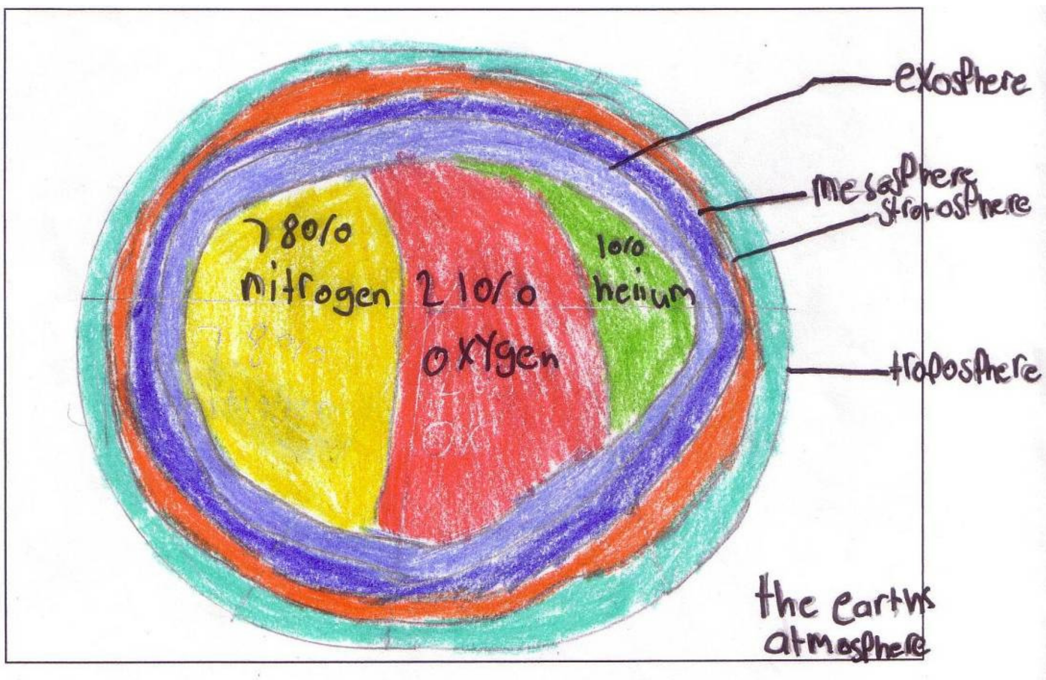


Figure 61. Pie chart showing chemical composition combined with a cross-section of the Earth's Atmosphere.

To confirm the accuracy of my sorting, I asked an impartial rater, an elementary school teacher with a Master's degree in Language and Literacy, to sort all 60 representations into categories, without indicating what those categories might be. She initially placed representations into categories she called 'showing numbers and showing layers' but quickly realized that those categories were not very descriptive. She noticed that some of the representations were pie charts and then began looking more closely at the form of the representations that showed layers. Her final categories were pie charts, drawings, layers, separate layers and pie charts, combined layers and pie charts, and bar graphs. Her placement of participants' representations into categories matched mine exactly although she used different names for those categories. I renamed my *other* category *bar graph* but made no other changes to my categorization of participants' representational form.

The forms of representations used by the 30 participants in the Parts of the Sun preassessment are shown in Table 31. The forms of representations used by participants in the Earth's Atmosphere postassessment are shown in Table 32. Overwhelmingly, participants elected to visually represent information in a cross-section, the most conventionally appropriate form of representation. A cross-section or cut-away was selected by 76.7% of the participants in the preassessment and 83.3% of the participants in the postassessment. These results indicated a high level of awareness of form and function, providing support for the SFL dimension of the exploratory framework. The high percentage of participants who chose to use a labelled diagram also indicated an awareness of disciplinary literacy (Shanahan & Shanahan, 2008) since diagrams are the most frequent form of visual representation in science information text (Unsworth, 2004).

Table 31

Forms of Representations Selected by Participants in the Preassessment

	Parts of the Sun (Preassessment)					
	Pic[a] *n* (%)	PC *n* (%)	XS *n* (%)	XS/PC separated *n* (%)	XS/PC combined *n* (%)	Bar graph *n* (%)
Ms. Arden[b]	2 (11.1)	1 (5.6)	7 (38.9)	6 (33.3)	1 (5.6)	1 (5.6)
Ms. Brown[c]	1 (8.3)	1 (8.3)	8 (66.7)	0	1 (8.3)	1 (8.3)
Total[d]	3 (10.0)	2 (6.7)	15 (50.0)	6 (20.0)	2 (6.7)	2 (6.7)

Note. [a] Pic = Picture; PC = Pie chart; XS = Cross-section or Cut-away. [b] *n* = 18. [c] *n* = 12. [d] 76.7% of the Grade 6 participants used labelled diagrams (cross-sections or cut-aways).

During the semistructured interviews, 24 participants either responded to questions about why they drew a particular representation or spontaneously described their decisions. These 24 responses and descriptions were coded; the results of the coding are shown in Table 33. Frequencies and examples are provided for each reason that participants gave to justify their selection of a particular form of visual representation.

Table 32

Forms of Representations Selected by Participants in the Postassessment

	Earth's Atmosphere (Postassessment)					
	Pic [a] *n* (%)	PC *n* (%)	XS *n* (%)	XS/PC separate *n* (%)	XS/PC combined *n* (%)	Bar graph *n* (%)
Ms. Arden[b]	0	2 (11.1)	10 (55.6)	5 (27.8)	1 (5.6)	0
Ms. Brown[c]	1 (8.3)	1 (8.3)	8 (66.7)	1 (8.3)	0	1 (8.3)
Total[d]	1 (3.3)	3 (10.0)	18 (60.0)	6 (20.0)	1 (3.3)	1 (3.3)

Note. [a] Pic = Picture; PC = Pie chart; XS = Cross-section or Cut-away. [b] *n* = 18. [c] *n* = 12. [d] 83.3% of the Grade 6 participants used labelled diagrams (cross-sections or cut-aways).

Table 33

Participants' Reasons for Selecting Particular Representational Forms

Reason	Instances *n*	%	Examples
			Form and Function
Best method	5	20.8	• *I thought it would kinda be better to show it from the inside, so kinda like cut in half.* • *I think the pie graph represented it better than, say, a bar graph.*
Disciplinary literacy	2	8.3	• *If you're visually representing something in a science class, it's always best to draw a labelled diagram.*
Shows information	9	37.5	• *It* [the diagram] *explains information and stuff.* • *I think diagrams represent, and you can get more information, represent more.*
			Metacognition
Memory	1	4.2	• *My very first encyclopaedia that somebody gave to me, it had a picture almost exactly like this* [cross-section with legend].
Personal preference	2	8.3	• *I don't like drawing pictures and that* [pointing to pie chart] *would be pretty easy.*
Quality of work	1	4.2	• *Just drawing a picture would be average and I like to do my work good and do extra.*
			Other
	4	16.7	• *It just seemed right.* • *I'm not sure.*
Total	24	100	

Participants' reasons for choosing to represent information in a particular form varied. While most responses shown in Table 33 appear to indicate some level of metacognitive awareness, particularly those responses coded *memory* and *quality of work*, several participants' responses also indicated that they were considering the appropriate form and function of a specific representation. For example, the responses coded *best method* and *shows information* indicate that those participants were considering SFL aspects. Some participants' responses suggest the interactive nature of the dimensions of metacognition and SFL, which was predicted in the structure of the 3D model of the exploratory framework. The responses that were coded and listed under the heading form and function (an aspect of SFL) also could be interpreted as suggesting that participants were engaged in some level of metacognition. However, the small number of participants in the verification study, and the even smaller number who articulated their reasons for representational choices, means that further research is needed to more fully examine the process of selecting a particular representational form.

Verification Study Theme 3: Participants' methods of planning for representing.

The third theme that emerged from my evaluation of participants' representations was planning for representing. While I was assessing participants' representations, I noticed that many students had used highlighters on the paragraphs of information. My curiosity about the ways in which students might have structured their reading experience in order to plan for visually representing led me to examine the assessment sheets more closely. During the semistructured interviews, I asked participants how they approached the task of reading and representing. A combination of observed and self-reported behaviours is discussed in this section.

My analysis of the assessment sheets revealed at least four methods that were used by participants to structure the reading experience or to prepare to construct a visual representation. These methods (i.e., tallying, numbering, making notes, and highlighting key words and phrases) are shown in Table 34, along with the frequencies of use. Highlighting (or circling or underlining) key words and phrases was the predominant method of structuring or planning as evidenced by a visual inspection of the assessment sheets. Only three participants used other methods of planning that could be seen on the assessment pages. The majority of the participants did not use any visible technique to prepare for constructing their representations.

Table 34
Evidence of Planning on the Assessment Sheet

	Pre (Parts of the Sun)			Post (Earth's Atmosphere)		
Evidence of planning	Ms. Arden *n* (%)	Ms. Brown *n* (%)	All *n* (%)	Ms. Arden *n* (%)	Ms. Brown *n* (%)	All *n* (%)
None	10 (55.6)	8 (66.7)	18 (60.0)	13 (72.2)	10 (83.3)	23 (76.7)
Tally marks	0	1 (8.3)	1 (3.3)	0	0	0
Numbers	0	1 (8.3)	1 (3.3)	0	0	0
Notes	0	1 (8.3)	1 (3.3)	0	0	0
Highlighting[a]	8 (44.4)	1 (8.3)	9 (30.0)	5 (27.8)	2 (16.7)	7 (23.3)
Total	18 (100)	12 (100)	30 (100)	18 (100)	12 (100)	30 (100)

Note. [a] Highlighting includes circling or underlining key words and phrases.

The lack of visible evidence of planning does not mean that participants did not plan; therefore, during the semistructured interviews, I asked students how they had proceeded through the assessment activity. Because students were given limited directions at the time of the assessments, they were free to approach the task in any number of ways. In my analysis of the transcriptions, I identified 28 instances in the pre- and postassessment interviews when participants responded in detail about their reading and representing process, and 22 of those instances related to reading. In 18 instances, participants reported that they had read all the paragraphs and then reread some or all of the information while they located the words and phrases they considered to be important. Only four participants specifically stated that they did not reread the paragraphs.

Strategies employed by the participants included:

- Read the entire passage, reread and highlight, then reread highlighted information while constructing the representation (4 instances). For example, one participant described his approach to the task as: *I read and then went back and reread and highlighted. I drew a picture after the main parts were highlighted.*

- Highlight while reading the passage for the first time, then reread (particularly highlighted information) and construct the representation (4 instances). One participant said, *Well, I read it once when I was highlighting it and I read it again*.
- Read the entire passage and then reread to locate appropriate information while constructing the representation (8 instances). One participant said, *I read the whole thing and then I drew a circle to start and then I read the first paragraph and drew that and then I read the second paragraph and drew that.*
- Make notes while reading the passage, then refer to notes while constructing the representation (2 instances). One participant who made notes stated*, I read through the whole thing and then looked through the notes to draw.*
- Read the entire passage, construct the representation without rereading (3 instances). For example, when asked if he had reread the information, one participant replied, *No, because I kinda already remembered what I read*.
- Begin reading the passage, start constructing the representation, and repeat until finished (1 instance). This participant said, *I was reading it and I was drawing at the same time.*

Planning for representing is related to the exploratory framework dimension of metacognition, which encompasses declarative (what), procedural (how), and conditional (why) knowledge. Participants were free to make choices about how to approach the assessment task rather than following a prescribed procedure because there were no directions provided during the task. Most participants who described their process used a rereading strategy and combined that approach with some means of identifying and highlighting important information. These results appear to support the inclusion of metacognition as an important aspect of the exploratory framework; however, further research is needed to explore the range of metacognitive strategies that students employ when constructing representations to communicate information.

Verification Study Theme 4: Participants' knowledge of conventions.

The fourth theme emerging from the analysis of participants' representations and semistructured interview responses is related to the criterion-based assessment of the representations described earlier in the chapter. However, it differs in that participants' knowledge of conventional aspects of labelled diagrams was revealed in three ways:

- *Analysis of representations*: I examined all representations for the inclusion of various components—some of which were part of the teachers' criteria for a labelled diagram (title, caption, labels, lines) and some of which were not (symbols, legend/key, arrows rather than lines).
- *Direct questioning*: I pointed to the components of the representation drawn by the participant and asked what those components were called (title, caption, labels, legend/key).
- *Transcript analysis*: I analyzed interview transcripts for participants' spontaneous use of visual representation terminology (e.g., graph, Venn diagram, pie chart).

Using these three approaches, I was able to develop more comprehensive inferences about participants' metacognitive awareness and knowledge of visual representations in general and labelled diagrams in particular. These inferences might provide support for the metacognitive and SFL dimensions of the exploratory framework or, alternatively, indicate the need for changes to the framework.

Analysis of representations.

The Parts of the Sun and Earth's Atmosphere representations were assessed using a checklist of components that are often associated with labelled diagrams. Use of particular components indicates that participants have an understanding of the conventions of visual representations, such as labelled diagrams, even if they are unable to identify what those components are. The use of specific components relies upon participants' procedural knowledge about visual representations and may indicate conditional knowledge if participants explicitly made decisions about the appropriateness of a component or a representation. Thus, the inclusion of specific components of a labelled diagram may provide support for the presence of a metacognitive dimension in the exploratory framework. The results of the checklist assessment are shown in Table 35. Labels were the most frequently used component in all cases. The graphs in Figures 62 through 64 appear to show a slight increase in participants' use of all components between the Parts of the Sun preassessment and the Earth's Atmosphere postassessment. However, chi-square analyses (X^2, cf. Isaac & Michael, 1997) revealed that only some of those increases were significant (see Table 36).

Table 35

Number of Participants Including Conventional Components of Labelled Diagrams in their Representations

Component	Pre (Parts of the Sun) Ms. Arden *n* (%)	Pre (Parts of the Sun) Ms. Brown *n* (%)	Pre (Parts of the Sun) All *n* (%)	Post (Earth's Atmosphere) Ms. Arden *n* (%)	Post (Earth's Atmosphere) Ms. Brown *n* (%)	Post (Earth's Atmosphere) All *n* (%)
No. of participants	18	12	30	18	12	30
Title	3 (16.7)	0	3 (10.0)	10 (55.6)	1 (8.3)	11 (36.7)
Caption	3 (16.7)	1 (8.3)	4 (13.3)	15 (83.3)	0	15 (50.0)
Labels	15 (83.3)	11 (91.7)	26 (86.7)	17 (94.4)	11 (91.7)	28 (93.3)
Lines/arrows	10 (55.6)	6 (50.0)	16 (53.3)	16 (88.9)	7 (58.3)	23 (76.7)
Symbols	8 (44.4)	3 (25.0)	11 (36.7)	10 (55.6)	5 (41.7)	15 (50.0)
Legend	2 (11.1)	2 (16.7)	4 (13.3)	3 (16.7)	0	3 (10.0)
None	2 (11.1)	1 (8.3)	3 (10.0)	0	1 (8.3)	1 (3.3)

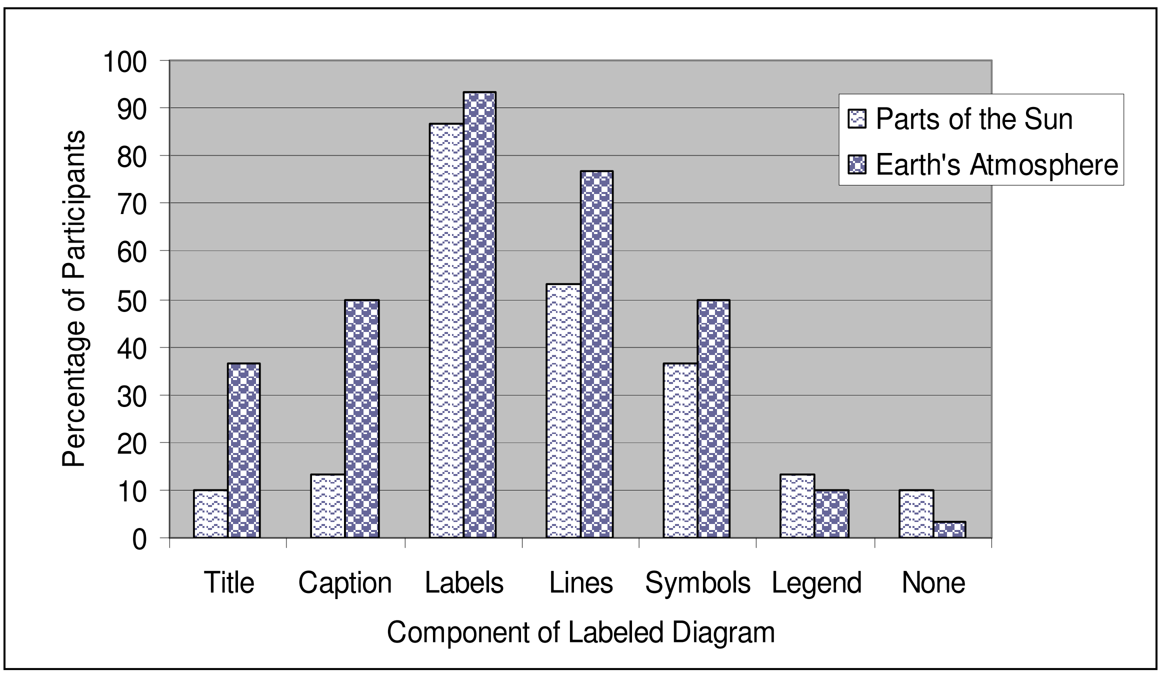


Figure 62. Percentage of all Grade 6 participants who included particular components in their representations (n = 30).

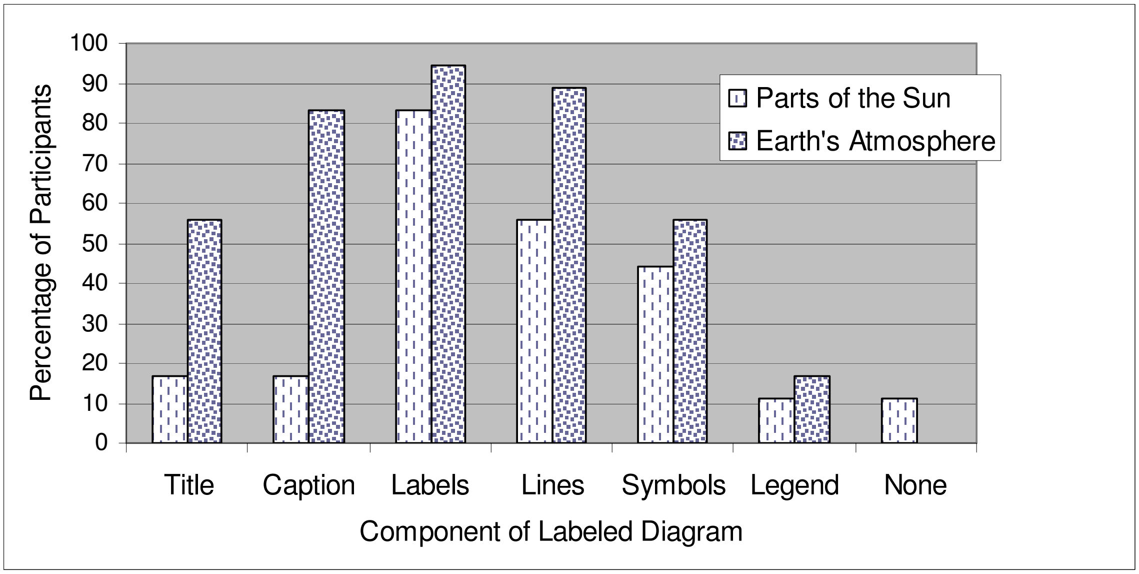


Figure 63. Percentage of participants in Ms. Arden's class who included particular components in their representations (n = 18).

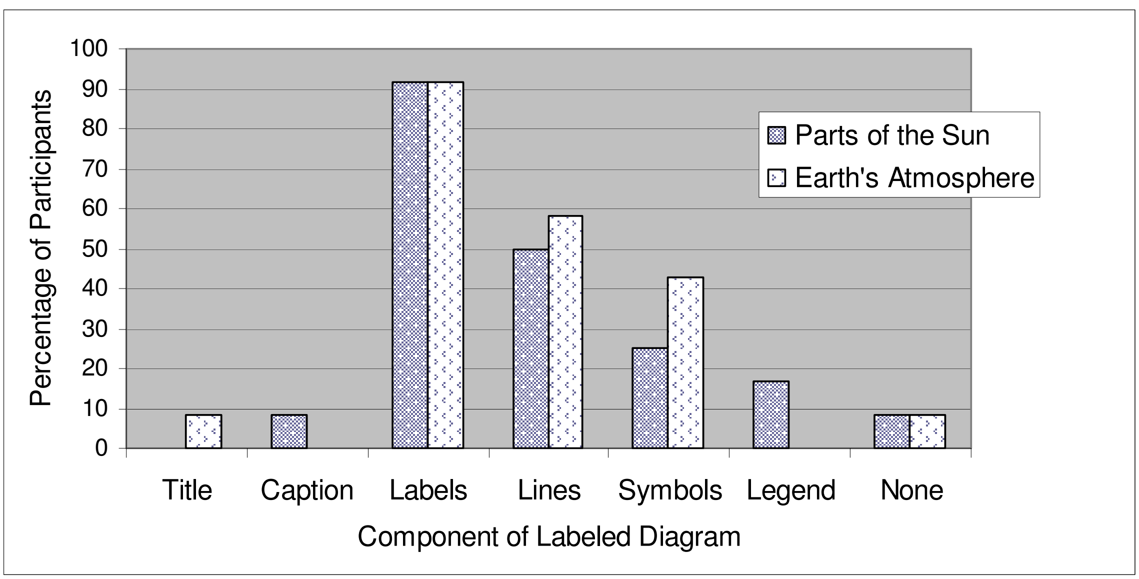


Figure 64. Percentage of participants in Ms. Brown's class who included particular components in their representations (n = 12).

Table 36
Results of a X^2 Analysis of Change in Participants' Use of Components

Component	All Grade 6 participants	Ms. Arden	Ms. Brown
Title	5.96^{b}	5.90^{b}	1.04
Caption	9.32^{c}	16.00^{c}	1.04
Labels	0.74	1.13	0.00
Lines	3.59	4.98^{a}	0.17
Symbols	1.09	0.44	0.75
Legend	0.16	0.23	2.18
None	1.07	2.12	0.00

Note. ^{a} $p = 0.050$; ^{b} $p = 0.020$; ^{c} $p = 0.01$

A statistically significant change was found in the use of titles and captions between the Parts of the Sun preassessment and the Earth's Atmosphere postassessment for all participants as well as for participants in Ms. Arden's class. A significant change was also found in the use of lines for participants in Ms. Arden's class. No significant changes were detected for participants in Ms. Brown's class. As always, the small number of participants should be kept in mind when considering these results because the quality (in this case, quantity) of the data influences the quality of the analyses.

Direct questioning.

The questions about components of visual representations were dependent upon the specific representation constructed by each participant. Correct use of a component indicates procedural knowledge and may also indicate conditional knowledge; correct identification of components indicates that participants have declarative knowledge about particular aspects of representations. Responses made in 22 preassessment interviews and 25 postassessment interviews provided information about participants' declarative knowledge.

Several participants displayed a knowledge and understanding of some specific aspects of visual representation but were unable to recall specific names. Two participants described Venn diagrams when asked about other types of diagrams they had drawn before and drew examples but could not recall the actual name. One particularly articulate student labelled his drawing and added a caption but did not know what these components were called. When asked what the labels were called, he replied, *I don't know the name but I put them on there because if I just did that* [the drawing] *then nobody would know which layer it is. They'd have to read through, so this is a quicker way to look at so I made it a little bit shorter*. When asked what his caption was, he responded, *I thought that was good information and there was no way I could put it in, well, I put it in there* [points at bottom]. In most cases, however, when participants included a particular component (e.g., a legend), they were able to name that component when asked, as shown in Figures 65 and 66.

Participants' utilization of specific aspects of visual representations supports the inclusion of an SFL dimension in the exploratory framework because this usage likely indicates knowledge of the form and function of representations. Knowing the conventions of particular representational forms and the functions of those forms is a key aspect of representational competence (Kozma & Russell, 2005b).

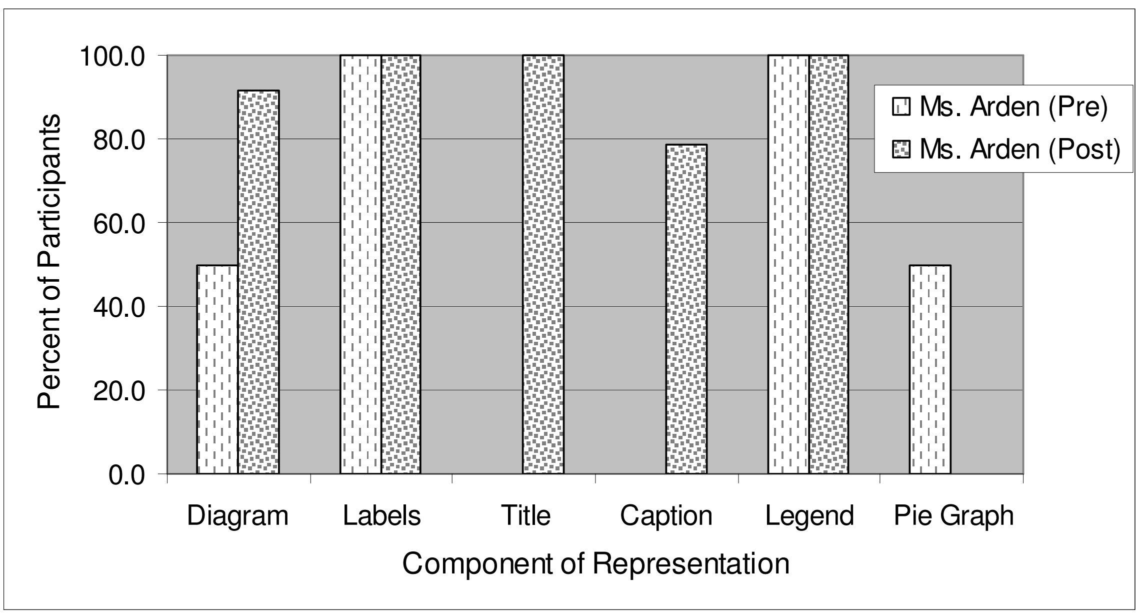


Figure 65. Percent of participants in Ms. Arden's class who correctly identified components of their representations.

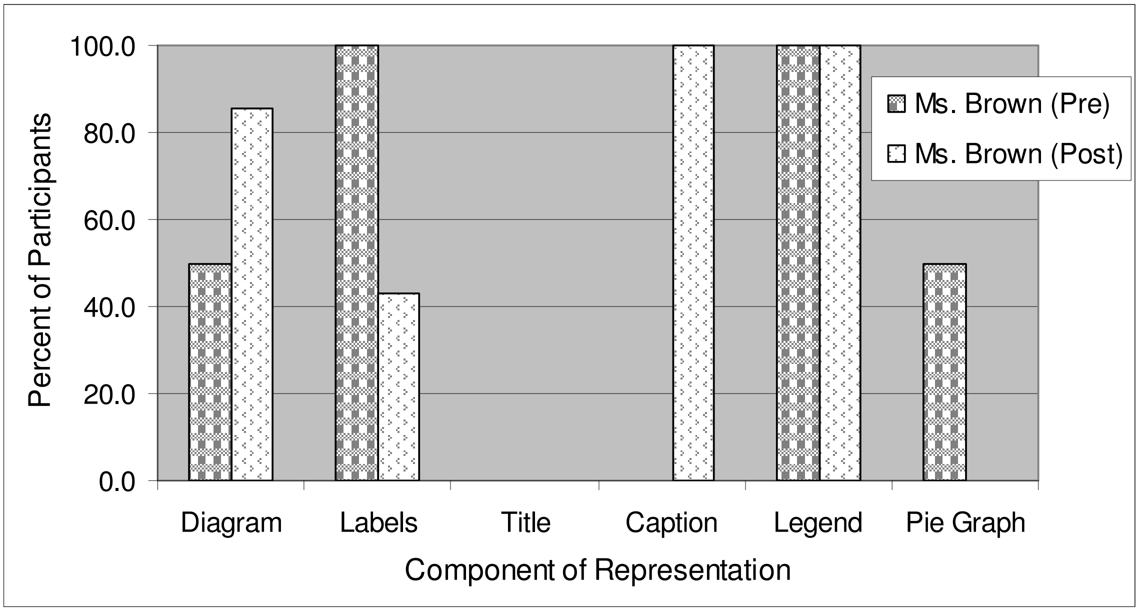


Figure 66. Percent of participants in Ms. Brown's class who correctly identified components of their representations.

Transcript analysis.

Participants who spontaneously used visual representation terminology during the semistructured interviews were indicating their declarative knowledge about aspects of representations, providing support for the inclusion of a metacognitive dimension to the exploratory framework. Instances of participants' spontaneous use of terminology are quantified in Table 37. During the 49 interviews, there were 12 instances in which participants spontaneously used terms relating to the form of a visual representation; these responses are coded as diagram, labelled diagram, Venn diagram, and graph or pie chart. Utilization of specific terms suggests that these participants had some declarative knowledge about visual representations; participants who did not use terminology unprompted may also have had declarative knowledge even though they did not demonstrate that knowledge spontaneously during the interview. There were 7 instances in which participants talked specifically about components of labelled diagrams; this higher level of specificity indicates more declarative knowledge and an awareness of form. Again, although unprompted usage of terminology implies a level of declarative knowledge, a lack of declarative knowledge is not suggested if the terms were not used spontaneously.

Table 37
Participants' Spontaneous Use of Visual Representation Terminology

Category	Instances *n*	%[a]	Examples
Form of visual representation			
Diagram	5	10.2	▪ *I thought I'd have to do a diagram.* ▪ *I just wrote and I thought and I drew diagrams of it.*
Labelled diagram	2	4.1	▪ *I'm not very artistic so I had to use a labelled diagram.* ▪ *When it says visually represent, I make a labelled diagram.*
Venn diagram[b]	2	4.1	▪ *Those circle diagrams … where it's like multiples of 2 and multiples of 4.* ▪ *Sometimes we would draw two pictures to compare them.*
Graph or pie chart	3	6.1	▪ *I think the pie graph represented it better than, say, a bar graph.* ▪ *I have a little pie chart.*
Components of labelled diagrams			
Labels	4	8.2	▪ *People might not know what things are supposed to be and the labels help the picture.* ▪ *I drew all of the rings of the atmospheres and then I labelled them.*
Title	1	2.1	▪ *I'd put a title on the top.*
Legend/Key	2	4.1	▪ *I like doing keys because I find it easier.* ▪ *Well I just found out all the stuff I needed to know, drew how many layers there were, drew the atmosphere and then drew a legend of what it was.*

Note. [a] % was calculated using the number of interviews (49); [b] Neither student actually recalled the name, but both described and drew Venn diagrams.

Examining the participants' representations and the interview transcriptions revealed that most participants had a sense of disciplinary literacy: the most appropriate representation of the information would be a labelled diagram, and a diagram was the most common form of representation used by participants. Several participants were able to articulate their reasons for selecting diagrams in general or cross-sections and cut-aways in particular. Responses to direct questioning indicated that most participants had a high level of declarative knowledge: most participants were able to accurately name the form and components of their representations. The use of various components of representations indicated participants' procedural and conditional knowledge: those participants who chose to include particular components demonstrated that they were aware of when and how to use particular components.

My visual analysis of the participants' representations, in conjunction with an analysis of participants' responses to direct questioning about components of their representations and participants' spontaneous use of representational terminology, indicates support for the inclusion of a metacognitive dimension in the exploratory framework. The metacognitive aspects of declarative, procedural, and conditional knowledge about visual representations in general, and labelled diagrams in particular, were evident in many participants' representations and during many of the semistructured interviews about those representations.

Verification Study Theme 5: Participants' selection of information to be represented.

The fifth and final theme emerging from my analysis of the representations and the interviews was the selection of information to be represented. I noted that while most participants represented the parts of the sun or the layers of the earth's atmosphere (i.e., information that formed the majority of the text passage) some participants represented the chemical composition in addition to or instead of the layers. During 17 of the interviews, there were 19 instances of participants describing their reasons for selecting particular information for representation. I followed an open-coding procedure (Flick, 2002) to analyze the reasons; the results of the coding process are shown in Table 38.

Participants' stated reasons for selecting particular information to represent appear to be contextual or metacognitive. Clues like the title or the vocabulary helped some participants to identify the information they thought should be represented. Other participants had pragmatic reasons for selecting information to represent; if they could not think of a way to represent information, they chose something else to represent.

Because there were so few instances in which participants did articulate their rationale for representing certain information, further investigation of the decision-making process is warranted in future studies. The results of the open-coding analysis suggested that participants' conditional knowledge was intuitive rather than

Table 38

Participants' Reasons for Selecting Information to Represent

Reason	Instances *n*	Instances %[a]	Examples
			Contextual clues
Title	1	5.2	▪ *That was the question* [points at title].
Vocabulary	2	10.5	▪ *Because it had the names of all the layers.* ▪ *It had, like, the names in brackets.*
Amount of information	5	26.3	▪ *There was a lot of stuff about the layers so I just decided to draw that.* ▪ *Most of the information was on the layers, so I focused on that.*
			Metacognitive rationale
Ability to represent	4	21.1	▪ *I didn't know how to draw that.* ▪ *I didn't find anything I could visually draw.*
Importance of information	3	15.8	▪ *That's pretty much what I thought was important.* ▪ *After I read it, I guess I dropped some stuff out that didn't seem that important.*
New or interesting information	2	10.5	▪ *Well, I just found that quite interesting.* ▪ *I decided not to show chemical composition because people might already know that.*
Other	2	10.5	▪ *To be able to fit the words in.* ▪ [shrug]
Total	19	99.9	

Note. [a] % was calculated using the number of instances (19).

formalized. The unformalized nature of participants' metacognition indicates that there is a need for explicit teaching of what, when, and how to use representations and components of representations. Future research could more rigorously investigate the extent of all three aspects of metacognitive knowledge and examine teaching strategies that might enhance students' metacognition. However, the results of the verification study do suggest support for including the metacognitive dimension of the exploratory framework because most participants who did articulate their decision-making rationale indicated that their choices were deliberate rather than arbitrary, which implies a metacognitive process.

Summary

Quantitative analyses revealed significant differences between all Grade 6 participants' pre- and postassessment representations when those representations were evaluated according to the teachers' criteria for a labelled diagram. Significant differences between pre- and postassessment were also found when representations were evaluated for levels of representational competence although there were no significant differences when other criteria (e.g., the initial rubric) were used. There were no significant gender differences regardless of the method of evaluating the representations, and there were no significant differences that might be related to participants' reading comprehension ability as measured by the DART. However, there were significant differences between the two classes when using the criterion-based evaluation and when assessing the level of representational competence. In addition, there was a statistically significant increase in frequency of use of titles and captions between the Parts of the Sun preassessment and the Earth's Atmosphere postassessment for all Grade 6 participants, likely due to the significant difference for participants in Ms. Arden's class. There was also a significant increase in the use of lines between pre- and postassessments for participants in Ms. Arden's class although there was no significant change overall for Grade 6 participants.

Teachers' responses to the SCIQ (Lewthwaite & Fisher, 2005) indicated that their perceptions and beliefs about teaching science were similar, suggesting that teacher beliefs did not contribute to any differences between classes. The qualitative coding of observations and audio-recordings of science lessons revealed that participants in the two classes experienced a difference in both number and frequency of type of episode. Although both teachers took an interactive-constructive approach to teaching and both teachers included activities and assignments that focused on visual representations, Ms. Arden's teaching appeared to emphasize visual literacy while Ms. Brown's teaching appeared to emphasize constructivist approaches. These teaching differences may be a result of differences in class composition and the level of adult support available rather than a difference in teacher beliefs about science instruction—since both teachers could be considered to take an interactive-constructive approach to instruction (Yore, 2001), and both teachers incorporated aspects of visual literary in their instruction.

Qualitative analyses suggested that many participants had beginning or intermediate levels of representational competence; most were at Levels 1, 2, or 3, according to Kozma and Russell's (2005b) description of five levels. Participants who described their decisions about adding color and selecting an appropriate form of representation revealed some metacognitive awareness (declarative, procedural, and conditional knowledge) as well as an awareness of the audience for the representation. Some participants demonstrated metacognitive awareness through their use of strategies for reading and locating information to be represented. Participants' representations revealed a sense of disciplinary literacy; the majority of participants selected a diagram of some sort as the most appropriate representation of the information they were given. Responses during the semistructured interviews indicated that most participants had some level of declarative and procedural knowledge about representations. Many participants who gave reasons for their selection of particular information to represent indicated that they were using contextual clues as well as metacognitive rationale to make those selections.

The results of qualitative and quantitative analyses indicated support for the inclusion of the two pedagogical dimensions of metacognition and SFL in the exploratory framework that was proposed in Chapter 3. My perspective while collecting and analyzing the data is likely to have influenced these findings, but the results do not negate the possibility that the two dimensions play important roles in the framework. Additionally, my analyses did not reveal the need for other dimensions to be included in the exploratory framework—although this result is influenced by my perspective during data collection and analysis. For example, it is likely that prior knowledge should be included in a theoretical framework for learning with representations, but the verification study did not examine the influence of prior knowledge.

In Chapter 7, I discuss the theoretical and pedagogical implications that arise from the results of the verification study. I highlight the connections between the literature review and the three components of the dissertation: the exploratory framework, the case-to-case synthesis, and the verification study.

Chapter 7
Discussion, Future Research, and Implications

In this chapter, I address the research questions that were stated in Chapter 1 and then describe the possible connections that may exist between the five themes that emerged from the verification study and the thematic review of the literature, the dimensions of the theoretical framework, and the themes from the case-to-case synthesis. I provide recommendations for future research and discuss the pedagogical, theoretical, and methodological implications that arise from this study.

Discussion

In this section, I systematically address my three original research questions and then highlight the relationship between the components of the dissertation. My research questions were: (1) *What are the key dimensions of an encompassing framework for learning with visual representations as indicated by a review of relevant literature, and how might those dimensions be related?* (2) *What common themes emerge from previous Pacific CRYSTAL case studies, and how might these themes relate to the exploratory framework?* (3) *What happens when students in Grade 6 are asked to construct visual representations based on unfamiliar science information text, and how do these results relate to the theoretical framework?*

Question 1 guided the development of the theoretical framework described in Chapter 3. A review of the literature (not to be confused with the thematic review, which comprises one particular aspect of that review) revealed that most of that literature focuses on learning from representations (e.g., Bezemer & Kress, 2008; Butcher, 2006; Schnotz & Bannert, 2003). However, an emphasis on learning from representations does not reflect how scientists use representations, nor does it reflect the role that constructing representations can play in enhancing understanding of concepts by learning with representations. In addition, published theoretical models and theories of learning are all intended to describe the cognitive processes that occur when one is reading and interpreting an already constructed representation —theories of learning from visual representations (e.g., Mayer, 2005a; Schnotz, 2002; Sweller & Chandler, 1991). There is no widely accepted theory of learning with visual representations. The four dimensions of the theoretical framework described in this dissertation were selected based upon extensive reading about visual representations in science and after extensive discussions around the preparations of conference presentations and publishing related articles about the results of a five-year-long community-based project that examined the purposeful embedding of literacy strategies and activities in middle school science classrooms (Pacific CRYSTAL). The relationship of the four dimensions still needs to be explored because the framework is a preliminary step in the development of a model or theory, rather than a fully developed and evidence-based model or theory.

The development of the literature-based framework provided a perspective from which to consolidate my thinking about constructivist views about representations in science. The framework itself could be beneficial as the field of learning from representations develops, helping to change research orientation from a traditional perspective of learning from representations to an interactive-constructive perspective of learning with representations, which requires a much greater reorientation than has been previously acknowledged (Yore & Hand, 2010). The theoretical framework also provided a lens for reconsidering the results of case studies that I had conducted previously.

Question 2 guided the case-to-case synthesis described in Chapter 4. The case-to-case synthesis, in turn, reflected and helped to shape the theoretical framework. The themes emerging from the case-to-case synthesis were the engaging and effective nature of multimedia genres, opportunities for differentiated instruction, opportunities for assessment, the important role of visual representations in science instruction, and the robust nature of some basic and intermediate literacy strategies (Shanahan & Shanahan, 2008) across disciplines. The affective potential of learning with multimedia or multimodal science texts may link to the motivational beliefs component of the metacognitive dimension of the theoretical framework (Dickson et al., 1998; see Figure 12 in Chapter 3). The potential for differentiated instruction does not appear to be related to any of the four dimensions. The theme of opportunities for assessment relates to the metacognitive and SFL dimensions of the framework because both of those dimensions could potentially inform student learning and classroom pedagogy, and assessment would be an important aspect of that pedagogy. The theme of visual representations' importance for learning in science instruction is supportive of the framework in general rather than any dimension in particular. The theme of the robust nature of literacy strategies across disciplines is a rather broad idea, but it could provide a link between the developmental nature of disciplinary literacy in general (Shanahan & Shanahan, 2008) and science literacy in particular (Yore et al., 2007).

Question 3 guided the verification study described in Chapters 5 and 6. The verification study was also informed by the theoretical framework and the earlier research that was described in the case-to-case synthesis. Despite the limitations of the mixed-methods verification study that were described in Chapter 1, there are a number of connections between the literature review, the case-to-case synthesis, the exploratory framework, and the results of the verification study. In the following sections, I highlight these connections, using the five themes that emerged from the verification study as an organizing structure.

Connections between the Components of the Dissertation

All themes emerging from the verification study are directly related to the literature review themes of learner-generated representations, classroom-based studies, and representational competence (see Appendix A for lists of studies that examined these aspects) because my study was situated in science classrooms and examined representations constructed by Grade 6 participants. The literature review theme of student agency is loosely connected to all themes from the verification study because students were free to make choices about how to best represent information. All themes emerging from the verification study are related to the case-to-case synthesis theme of the importance of visual representations in science instruction. These general and overarching connections are not emphasized in the sections below; however, specific aspects of these themes are discussed where appropriate. All connections among the three components of the dissertation (theoretical framework, metasynthesis, verification study) and the thematic review of the literature are shown in Figure M1 in Appendix M.

Verification Study Theme: Participants' methods of planning for representing.

The first theme revealed was the strategic planning for representation that was demonstrated by some participants. The visible evidence that participants were planning for representing before, during, and after reading a science information passage included highlighting, circling, underlining, and tallying. Some students were enacting their metacognitive awareness (declarative and procedural knowledge about representing) into strategic actions to identify main ideas, important details, and qualifying information in preparation for representing these selected aspects in a diagram. Participants' comments during semistructured interviews provided indications of self-management or executive control. These indications of planning are directly related to the metacognitive dimension of the exploratory framework.

There are no obvious connections between this theme and the thematic review of the literature other than the three general connections stated earlier. However, the theme of strategic preparation is closely connected to the metasynthesis theme of teaching about representations because metacognitive strategy use is a potential area for improved pedagogy (USNRC, 2005). Teachers might provide explicit instruction about specific metacognitive strategies that students could learn, practice, and master as they constructed and interpreted visual representations.

Verification Study Theme: Participants' selection of information to be represented.

A second theme that emerged from the verification study was participants' selection of information. Interviews revealed that many participants made choices about which information to represent based on their understanding of the content and of the conventions for representing that content, thus relying on both the derived and the fundamental aspects of science literacy (Yore et al., 2008). Selection of information connects to the metasynthesis theme of assessment because students' identification of main ideas and supporting details provides teachers with an indication of students' knowledge of those ideas.

Participants' knowledge of how to represent information included an awareness of form and function and, therefore, connects to the SFL dimension of the exploratory framework; however, the selection of information is most strongly connected to the metacognition dimension of the exploratory framework. Participants who articulated their decisions about selecting information gave responses that indicated metacognitive processes that likely involved declarative, procedural, and conditional knowledge as participants planned, monitored, and adjusted strategies during construction of their representations. The decision making likely would also involve participants' content knowledge and their understanding of the target concepts (Moje, 2008). However, the design of the verification study did not include measures of participants' prior knowledge.

Verification Study Theme: Participants' choice of representation (form and function).

A third theme from the verification study was participants' choice of representation based on form and function. With few exceptions, participants selected a representational form that would facilitate the communication of information rather than creating a picture that might capture aesthetic aspects of the target topic, which likely reflected conditional knowledge of visual representations. Pie charts were frequently used to communicate the chemical composition of the sun and of the Earth's atmosphere while a labelled diagram was used to show the layers of the sun and of the Earth's atmosphere. Participants' understanding of the functions of various forms of representation tended to be intuitive; however, few participants were able to articulate why some representations were more suited for particular purposes. This theme connects with the literature review theme of learning from visual representations because knowledge of specific forms and the functions of those forms is a critical aspect of being able to correctly interpret visual representations (e.g., Pintó & Ametller, 2002).

Form and function connects with the literature review theme of assessment opportunities and the case-to-case synthesis theme of opportunities for assessment because students' ability to correctly select a form for representing information is a basic requirement for correctly representing information. Teachers can assess aspects of students' representational competence such as how and when students are able to select and use particular forms of representations.

The form and function of representations is directly linked to the semiotics and SFL dimensions of the exploratory framework with the SFL dimension affording pedagogical opportunities and a link to the important role of visual representations that emerged from the case-to-case synthesis. Choosing a particular representational form for a particular function would also involve metacognitive processes, such as thinking about the purpose of a representation or being aware of potential audiences; thus, this theme also links to the metacognitive dimension of the exploratory framework.

Verification Study Theme: Participants' use of color.

A fourth theme that emerged was participants' use of color. Many participants chose to use color when representing the parts of the sun or the layers of the Earth, and their reasons for doing so revealed a growing awareness of the affordances of color as a tool for communicating information. Most participants who used color were attempting to differentiate between aspects of a representation or to direct attention towards particular parts of a representation, as was revealed by their interview responses. The Grade 6 participants' intuitive use of color reflects an aspect of representational competence that was uncovered in the literature review; several authors have noted students' innate, though often limited, understanding of representational conventions (e.g., diSessa & Sherin, 2000).

Use of color can be connected with an understanding of conventions, which in turn connects with the literature review theme of assessment opportunities and the case-to-case synthesis theme of opportunities for assessment. Criteria for representational activities could include the use of specific components and conventions that would be appropriate for communicating particular information.

The participants' use of color as a communication tool fits within the dimension of SFL in the exploratory framework because it is an aspect of function. It is also connected to the metasynthesis theme of teaching about representations since a naïve understanding of color could be used by teachers as a starting point for learning more about the affordances of specific aspects of various representational forms.

Verification Study Theme: Participants' knowledge of conventions.

A fifth theme from the verification study was participants' knowledge of the conventions of labelled diagrams in particular. Visual representations are powerful tools for communicating information only if one knows the codes and conventions for interpreting and constructing images (Pintó & Ametller, 2002). The results of the verification study, in particular the statistically significant differences between representations of the participants in the two Grade 6 classes, indicated that conventions such as which components are necessary or helpful can be taught. An increased emphasis on visual representations and explicit discussion of the functions, components, and conventions of those representations was related to more frequent use of components. Knowledge of a range of cultural conventions, and how those conventions might be used, is a specific aspect of representational competence (diSessa & Sherin, 2000) and is directly related to the SFL dimension of the exploratory framework (Fang, 2005, 2006). This theme also connects to the case-to-case metasynthesis theme of the importance of teaching about visual representations in science. Students' representational competence is more likely to improve if science is taught in a representation-rich learning environment (Hubber et al., 2010) and that environment should include explicit instruction about the functions, components, and conventions of representations.

Recommendations for Future Research

The literature review, combined with the case-to-case synthesis and the results of the verification study, suggest several directions for future research. Further research is needed to more fully describe (1) how students in classroom settings construct understanding *with* visual representations, (2) how students construct their own visual representations of science concepts as their representational competence and domain knowledge progresses, and (3) how the construction of such representations affects the subsequent understanding of science concepts. Such future research could help to refine or validate the exploratory framework.

Future research might more closely examine students' knowledge of the range of representations frequently used in science information text (e.g., labelled diagrams, Venn diagrams, flowcharts, bar graphs) and of the specialized conventions of each form. Further research exploring the changes in representational competence and conceptual understanding that may occur when students engage in negotiating representational conventions is warranted. Students' ability to create particular representations to communicate and construct science understandings could be explored.

Further research is needed to explore the range of metacognitive strategies that students employ when using representations to construct, understand, and communicate information and to determine instructional approaches to help students develop a repertoire of useful strategies. Examples of strategies that could be more closely examined include self-explanation or think-alouds (e.g., Ainsworth & Loizou, 2003; Butcher, 2006). Future research could clarify how and why participants choose particular representations and examine students' reasoning about the best representation for particular kinds of information. The high number of correct responses to direct questioning about components of specific representations indicated that most participants had a high level of declarative knowledge, and future research could more rigorously examine the extent of that declarative knowledge.

A third area that should be investigated in future research is the impact of constructing representations upon conceptual growth and change. This research could examine how students' understanding might be facilitated when learning *with* rather than *from* representations. The potential for conceptual growth and change when transforming between and among representational modes could be explored.

Theoretical and Methodological Contributions

Although further research examining the use of visual elements is certainly warranted, there are a number of implications that arise from the verification study and its related components. The importance of visual literacy, specifically interpreting and constructing visual representations, is widely acknowledged in science education literature and has been highlighted by recent special issues of the *International Journal of Science Education* (2009) and *Research in Science Education* (2010). Traditionally, textbooks and trade books have been the most common sources of information in the science classroom. The increasing availability of electronic texts means that many students have opportunities to learn with dynamic representations of science concepts. Middle school students who read and construct multimodal science information text, whether that text is print or electronic, will encounter a wide variety of visual representations, both static and dynamic, and require increasing degrees of representational competence as they engage in intermediate or disciplinary literacy activities (Moje, 2008; Shanahan & Shanahan, 2008). However, limited research has examined younger students' representational competence; few studies have been situated in classrooms rather than alternative settings; and a comprehensive theoretical framework for learning *with* representations has yet to be adopted. The exploratory framework and the results of the empirical research described here are likely to contribute to the literature on visual representations in several ways.

Personal communications with a number of experts at the 2010 conference of the Text and Graphics special interest group of the European Association for Research in Learning and Instruction suggest the need for more explicit emphasis on those aspects of visual literacy that are particularly relevant for science learning, such as representational competence, which includes knowledge of conventions, use of multiple representations, and problem-solving with representations. Experts communicated that visual literacy and/or representational competence was assumed to be important but that little attention had been paid to classroom instruction. There is no widely accepted theoretical model that describes learning with representations. In addition, there is as yet no agreed-upon measure of representational competence (e.g., deVries & Lowe, 2010). The framework described in Chapter 3 could be the preliminary stage in the development of such a model. Attempts to examine aspects of representational competence revealed by the verification study, such as knowledge of the components of labelled diagrams, might provide the beginning of the development of a measure of representational competence.

The dissertation, especially the theoretical framework, contributes to theoretical aspects of learning *with* representations. Although there are several cognitive models proposed for learning *from* representations, there is no widely accepted comprehensive theoretical framework that holds explanatory powers for learning with visual representations in multimedia texts and transforming information from one representational mode to another. The exploratory framework, which integrates cognition, metacognition, semiotics, and SFL, could eventually result in a model that might be used to guide classroom practice, leading to improved visual literacy, better comprehension of science concepts, and enhanced science literacy because it emphasizes distinct aspects of learning with representations that can be addressed though explicit instruction. For example, metacognition and metacognitive skills are frequently mentioned in discussions of language and literacy instruction (e.g., Tompkins et al., 2008) and should also be a component of science literacy. To date, however, there has been little attention paid to the importance of metacognition in science literacy (Ford & Yore, in press).

The dissertation makes a methodological contribution to the literature on visual representations in science. The study took place in middle school classrooms during regular instruction, in contrast to more common laboratory-based research programs that typically involve university students in highly controlled environments. The results of research conducted under more authentic conditions provide a clearer understanding of what is possible in science classrooms, which are complex and multidimensional spaces and which include multiple literacies (New London Group, 1996).

Pedagogical Implications

The dissertation has implications for two complementary aspects of classroom pedagogy. The results of the verification study add to what we know about the representational competence of Grade 6 students and provide insights about effective classroom instruction in science that includes a representation-rich environment. This enhanced understanding could ultimately lead to improvements in classroom practices and instructional materials. Visual representations are ubiquitous in science information text and middle school students are likely to benefit from explicit instruction about the representations that they will encounter while reading such text (e.g., Unsworth, 2004; Waldrip et al., 2010). Classroom teachers who are more aware of the cognitive demands placed on their students will likely recognize the need for explicit instruction about the many visual representations embedded in science texts, making their classroom practice more effective. The benefits of explicit instruction are indicated both by the results of the literature review (e.g., Chandrasegaran et al., 2008) and by the results of the verification study. Teaching efforts should scaffold student discussion of how to represent concepts and ideas rather than emphasize memorization of particular representations and conventions.

However, the power of visual representations in science lies in learning *with* rather than simply *from* representations (note that *with* is inclusive and does not preclude learning from prepared or canonical images). With regard to constructivist perspectives on teaching and learning, most of the participants in this study were able to identify important information and to select appropriate forms of representations to communicate that information. The participants' understanding that certain forms might be best used to represent particular information would be the starting point in constructivist pedagogy intended to facilitate growth in representational competence. Once one understands that there is a link between form and function; a range of forms and functions can be more closely examined, critiqued, and incorporated into one's repertoire. Positioning color as a communication tool, for example, could provide a starting point for discussion of other tools or conventions, such as arrows, lines, and symbols.

Explicit instruction about visual representations and their functions and conventions is likely to lead to increased understanding of the science concepts in those representations as well as increased representational competence (diSessa, 2004). The effect of repeated explicit instruction was suggested by the results of the verification study; class-level differences between pre- and postinstruction assessments may have been related to the instructional differences between classes. The differences in teaching episodes between the two teachers suggests that providing students with repeated experiences with a variety of representations, both static and dynamic, can facilitate the growth of students' representational competence and facilitate translation between modes.

Although teaching with a representational focus reflects the nature of science, there are two cautions arising from the literature review and the verification study. First, when teaching with visual representations, there is the risk of developing a stagnant canon of specific representations (diSessa, 2004) or of producing a static grammar of modes (Jewitt, 2008). However, Moje (2008) pointed out that experts often reconstruct rules of disciplinary discourse. Rather than presenting students with representations to be memorized, teachers should support students as they engage in negotiations about how best to represent concepts. Additionally, representations should be evaluated and compared and the design of new ways to represent information should be encouraged.

Second, although the continuum of disciplinary literacy described by Shanahan and Shanahan (2008) is a useful way to conceptualize science literacy, domain-specific instruction about language conventions must be carefully presented to students. If the focus of classroom instruction is perceived by students to be discipline-specific literacy techniques rather than more generalizable intermediate literacy practices, the strategies may not be utilized in different, albeit appropriate, domains. An example of this disciplinary constraint was revealed in an informal conversation with Ms. Arden where she reported that her students did not do well on spring DART questions that involved drawing a diagram. When she discussed the DART results with her students, they responded that of course they knew how to draw labelled diagrams … in science! Few of the students were noted to have transferred their knowledge of conventions of labelled diagrams in science to the DART, which students classified as a language arts test. Students learning about how the disciplinary discourses are different should be encouraged to consider similarities within those discourses.

Visual representations are omnipresent in children's science information text; however, teachers do not always use visual elements to maximum advantage (Smolkin & Donovan, 2002). Because of the complex nature of science information text, if children are to comprehend and remember as much information as possible, teachers need to provide explicit, just-in-time instruction about the forms and functions of the visual representations students encounter while reading such texts. For example, each type of visual representation has specific conventions and characteristics that influence how the information that is contained in the representation will be comprehended.

Children need multiple opportunities to interpret visual representations while receiving appropriate levels of support from the teacher before they are able to develop the cognitive skills required for maximum comprehension of information. In addition, tasks involving the use or creation of visual representations should reflect real-world applications (Verdi & Kulhavy, 2002). Children who understand the purpose or meaning of assigned activities are more likely to be engaged in those activities than children who do not comprehend the purpose of the activities in which they are asked to participate.

Teachers should exercise caution when designing their own visual representations to enhance and supplement science concepts. Visual elements should be designed to facilitate comprehension rather than to enhance the aesthetic appeal of text; therefore, illustrations should be representational, organizational, or interpretational rather than decorational (Carney & Levin, 2002).

Concluding Remarks

Disciplinary literacy means being able to use a particular range of representational modes to construct and communicate knowledge (Moje, 2008). A combination of words and images constructs and represents science as known by scientists and shapes student understanding of science. If students are to develop representational competence and become expert users of the representations that are a key component of science information text, they need to understand the forms of representations and the conventions of those forms; the relationship between a representation and the information it represents; the importance of choosing and constructing the most appropriate form of representation; and the ways in which representations can be integrated with, transformed, and related to one another (Ainsworth, 2008). In addition, representational competence includes knowing how to invent new ways of representing information, how to evaluate and compare representations, and how representations are situated within a culturally constructed and discipline-specific discourse (diSessa & Sherin, 2000).

The development of representational competence is a lengthy process that spans the range from novice to expert. Development is likely to be facilitated by explicit instruction as well as immersion in scientific discourse practices that include reading, writing, viewing, and representing (Gee, 2005). Hubber et al. (2010) proposed a number of principles for designing an effective force and motion unit with a strong representational focus. Based on the proposed exploratory framework and drawing on results from the verification study, I reworded these principles to make them applicable to any science topic or unit that is intended to enhance students' representational competence. Ranging from student-centered to teacher-focused principles, these general representational principles include:

- Students should be encouraged to create their own representations.
- Representations should be connected with hands-on experiences of the topic under investigation.
- Teachers should support students in discussing and developing conventions for communicating information through representations.
- Multiple representations, in a variety of appropriate forms and modes, should be introduced throughout a unit as needed.
- Representations should be conceptualized as tools for thinking, learning, and communicating rather than as items to copy and memorize.
- Teachers should support explicit discussion about multiple representations and help students to evaluate the usefulness of particular representational forms.

Multiple representations are common in children's science information text; if children are to comprehend and consolidate as much information as possible, they need explicit instruction about the representations that they will encounter while reading such texts. In order to construct understanding and communicate information, students must be given opportunities to negotiate conventions in the context of hands-on experiences. Frequent opportunities to transform from one representational mode to another, for example, from a table to a graph to a diagram, will allow students to develop a higher level of representational competence (e.g., Pérez Echeverría et al., 2010).

There is a continuum of visual literacy abilities from identifying the subject of a representation, through comprehending the concepts depicted in a representation, to being able to use representations in an expert manner (Gilbert, 2008). Comprehension requires critical thinking and metacognitive skills and strategies—as does expertise in a domain or discipline (Tompkins et al., 2008). Metacognitive strategies, such as checking for understanding, should be an explicit component of any instructional program.

In order to make meaning from scientific texts, both words and images must be read, which requires a high level of visual literacy. When words and images convey similar or related information, they act as multiple representations or, more specifically, multimedia messages. Reading visual representations is a life skill—adults most frequently read informational or expository text, text that is often laden with visual elements, both static and dynamic (Moline, 1995). Perhaps more importantly, making meaning *with* multimodal texts, constructing representations to strengthen understanding of science concepts, and communicating information through visual representations all require representational competence, making representational competence a critical component of science literacy and, therefore, of science education.

References

Aanstoos, J. (2003). Visual literacy: An overview. *Proceedings of the 32nd Applied Imagery Pattern Recognition Workshop*, 189-193. doi:10.1109/AIPR.2003.1284270

Abell, S. K., & Volkmann, M. J. (2006). *Seamless assessment in science: A guide for elementary and middle school teachers*. Portsmouth, NH: National Science Teachers Association.

Acher, A., & Arcà, M. (2010). Children's representations in modeling scientific knowledge construction. In C. Andersen, N. Scheuer, M. P. Pérez Echeverría, & E. V. Teubal (Eds.), *Representational systems and practices as learning tools* (pp. 109-131). Boston, MA: Sense.

Adadan, E., Irving, K. E., & Trundle, K. C. (2009). Impacts of multi-representational instruction on high school students' conceptual understandings of the particulate nature of matter. *International Journal of Science Education, 31*, 1743-1775. doi:10.1080/09500690802178628

Ainsworth, S. (1999). The functions of multiple representations. *Computers and Education, 33*, 131-152.

Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction, 16*, 183-198. doi:10.1016/j.learninstruc.2006.03.001

Ainsworth, S. (2008). The educational value of multiple-representations when learning complex scientific concepts. In J. Gilbert, M. Reiner, & M. Nakhleh (Eds.), *Visualization: Theory and practice in science education* (pp. 191-208). New York, NY: Springer.

Ainsworth, S., & Loizou, A. (2003). The effects of self-explaining when learning with text or diagrams. *Cognitive Science, 27*, 669-681. doi:10.1207/s15516709cog2704_5

Ainsworth, S., Galpin, J., & Musgrove, S. (2007, September). *Learning about dynamic systems by drawing for yourself and for others*. Paper presented at the 6th biennial conference of the European Science Education Research Association, Budapest, Hungary.

Amare, N., & Manning, A. (2007). The language of visuals: Text + graphics = visual rhetoric. *IEEE Transactions on Professional Communication, 50*, 57-70.

Ametller, J., & Pintó, R. (2002). Students' reading of innovative images of energy at secondary school level. *International Journal of Science Education, 24*, 285-312. doi:10.1080/09500690110078914

Anstey, M., & Bull, G. (2006). *Teaching and learning multiliteracies: Changing times, changing literacies*. Newark, DE: International Reading Association.

Anthony, R. J., Tippett, C. D., & Yore, L. D. (2010). Pacific CRYSTAL project: Explicit literacy instruction embedded in middle school science classrooms. *Research in Science Education, 40,* 45-64. doi:10.1007/s11165-009-9156-7

Arizona Collaborative for Excellence in Preparation of Teachers. (2000). *Reformed Teaching Observation Protocol (RTOP): Reference manual (ACEPT IN-003)*. Arizona State University, Tempe. Retrieved from http://physicsed.buffalostate.edu/AZTEC/rtop/RTOP_full/PDF/RTOP_ref_man_IN003.pdf

Armbruster, B. B., Anderson, T. H., & Ostertag, J. (1987). Does text structure/summarization instruction facilitate learning from expository text? *Reading Research Quarterly, 22,* 331-346.

Atkinson, T. S., Matusevich, M. N., & Huber, L. (2009). Making science trade book choices for elementary classrooms. *The Reading Teacher, 62*, 484-497. doi:10.1598/RT.62.6.3

Avgerinou, M., & Ericson, J. (1997). A review of the concept of visual literacy. *British Journal of Educational Technology, 28*, 280-291.

Ayres, P., & Sweller, J. (2005). The split-attention principle in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 135-146). New York, NY: Cambridge University Press.

Baddeley, A. D. (1992). Working memory. *Science, 255* (5044), 556-559.

Baddeley, A. D., & Hitch, G. (1977). Working memory. In G. Bower (Ed.), *Human memory: Basic processes* (pp. 199-241). New York, NY: Academic. (Reprinted from *The Psychology of Learning and Motivation*, 1974, 8, 47-89)

Bamford, A. (2003). *The visual literacy white paper*. Retrieved from http://www.adobe.com/uk/education/pdf/adobe_visual_literacy_paper.pdf

Bandura, A. (2000). Exercise of human agency through collective efficacy. *Current Directions in Psychological Science, 9*(3), 75-78.

Begoray, D. (2000). Seventy plus ideas for viewing and representing (and they're not just for language arts!). *English Quarterly, 32*(1&2), 30-39.

Best, R., Dockrell, J., & Braisby, N. (2010). Children's semantic representations of a science term. In C. Andersen, N. Scheuer, M. P. Pérez Echeverría, & E. V. Teubal (Eds.), *Representational systems and practices as learning tools* (pp. 93-108). Boston, MA: Sense.

Betrancourt, M., Dilenbourg, P., & Clavien, L. (2008). Display of key pictures from animation: Effects on learning. In J.-F. Rouet, R. Lowe, & W. Schnotz (Eds.), *Understanding multimedia documents* (pp. 61-78). doi:10.1007/978-0-387-73337-1_4

Bezemer, J., & Kress, G. (2008). Writing in multimodal texts: A social semiotic account of designs for learning. *Written Communication, 25*, 166-195. doi:10.1177/0741088307313177

Black Cockatoo Publishing. (2006). What is visual literacy? Retrieved from http://k-8visual.info/whatis_Text.html

Bodemer, D., & Faust, U. (2006). External and mental referencing of multiple representations. *Computers in Human Behavior, 22*, 27-42. doi:10.1016/j.chb.2005.01.00

Botzer, G., & Reiner, M. (2007). Imagery in physics learning — from physicists' practice to naïve students' understanding. In J. K. Gilbert (Ed.), *Visualization in science education* (pp. 147-168). Dordrecht, The Netherlands: Springer.

Boyatzis, R. E. (1998). *Transforming qualitative information: Thematic analysis and code development*. Thousand Oaks, CA: Sage.

Breckon, C. J., Jones, L. J., & Moorhouse, C. E. (1987). *Visual messages: An introduction to graphics*. Newton Abbot, United Kingdom: David & Charles.

Bringuier, J. (1980). *Conversations with Jean Piaget* (B. Gulati, Trans.). Chicago, IL: University of Chicago Press. (Original work published 1977)

Brooks, M. (2009). Drawing, visualisation and young children's exploration of "big ideas". *International Journal of Science Education, 31*, 319-341. doi:10-1080/09500690802595771

Butcher, K. (2006). Learning from text with diagrams: Promoting mental model development and inference generation. *Journal of Educational Psychology, 98*, 182-197.

Camp, J. (2003). Concurrent and retrospective verbal reports as tools to better understand the role of attention in second language tasks. *International Journal of Applied Linguistics, 2*, 201-221.

Carney, R. N., & Levin, J. R. (2002). Pictorial illustrations *still* improve students' learning from text. *Educational Psychological Review, 14*(1), 5-26.

Carolan, J., Prain, V., & Waldrip, B. (2008). Using representations for teaching and learning in science. *Teaching Science, 54*(1), 18-23.

Chandrasegaran, A. L., Treagust, D. F., & Mocerino, M. (2008). An evaluation of a teaching intervention to promote students' ability to use multiple levels of representation when describing and explaining chemical reactions. *Research in Science Education, 38*, 237-248.

Chittleborough, G., & Treagust, D. F. (2008). Correct interpretation of chemical diagrams requires transforming from one level of representation to another. *Research in Science Education, 38*, 463-482.

Colin, P., Chauvet, F., & Viennot, L. (2002). Reading images in optics: Students' difficulties and teachers' views. *International Journal of Science Education, 24*, 313-332. doi:10.1080/09500690110078923

Cook, L. K., & Mayer, R. E. (1988). Teaching readers about the structure of scientific text. *Journal of Educational Psychology, 80*, 448-456.

Cook, M., Carter, G., & Wiebe, E. (2008). The interpretation of cellular transport graphics by students with low and high prior knowledge. *International Journal of Science Education, 30*, 239-261. doi:10.1080/09500690601187168

Council of Ministers of Education, Canada. (1997). *The common framework of science learning outcomes K-12: Pan-Canadian protocol for collaboration on school curriculum*. Retrieved from http://www.cmec.ca/science/framework/

Creswell, J. (2003). *Research design: Qualitative, quantitative, and mixed methods approaches* (2nd ed.). Thousand Oaks, CA: Sage.

Creswell, J., & Plano Clark, V. (2007). *Designing and conducting mixed methods research*. Thousand Oaks, CA: Sage.

Dale, E., & Chall, J. S. (1948a). A formula for predicting readability. *Educational Research Bulletin, 27*(1), 11-20 & 28.

Dale, E., & Chall, J. S. (1948b). A formula for predicting readability: Instructions. *Educational Research Bulletin, 27*(1), 37-54.

de Jong, T., Ainsworth, S., Dobson, M., van der Hulst, A., Levonen, J., Reimann, P., ... Swaak, J. (1998). Acquiring knowledge in science and mathematics: The use of multiple representations in technology-based learning environments. In M. W. van Someren, P. Reimann, H. P. A. Boshuizen, & T. de Jong (Eds.), *Learning with multiple representations* (pp. 9-40). New York, NY: Elsevier Science.

de Vries, E., & Lowe, R. (2010). *Graphicacy: What does the learner bring to a graphic?* Paper presented at the biennial conference of the European Association for Research on Learning and Instruction Special Interest Group (Text and Graphics), Tübingen, Germany.

de Vries, E., Demetriadis, S., & Ainsworth, S. (2009). Learning with external representations: Headed towards a digital culture. In N. Balacheff, S. Ludvigsen, T. de Jong, A. Lazonder, & S. Barnes (Eds.), *Technology enhanced learning – Principles and products* (pp. 137-153). Heidelberg, Germany: Springer.

Debes, J. L. (1969). The loom of visual literacy: An overview. *Audiovisual Instruction, 14*(8), 25-27.

Decoito, I. (2006). Innovations in science education: Challenging and changing teachers' roles and beliefs. *Canadian Journal of Science, Mathematics, and Technology Education, 6*, 339-350.

Denzin, N. K., & Lincoln, Y. S. (Eds.). (2000). *Handbook of qualitative research* (2nd ed.). Thousand Oaks, CA: Sage.

Denzin, N. K., Lincoln, Y. S., & Giardina, M. D. (2006). Disciplining qualitative research. *International Journal of Qualitative Studies in Education, 19*, 769-782. doi:10.1080/09518390600975990

Dickson, S. V., Collins, V. L., Simmons, D. C., & Kameenui, E. J. (1998). Metacognitive strategies: Research bases. In D. C. Simmons & E. J. Kameenui (Eds.), *What reading research tells us about children with diverse learning needs* (pp. 295-360). Mahwah, NJ: Lawrence Erlbaum.

diSessa, A. (2004). Metarepresentation: Native competence and targets for instruction. *Cognition and Instruction, 22*, 293-331.

diSessa, A., & Sherin, B. (2000). Metarepresentation: An introduction. *The Journal of Mathematical Behavior, 19*, 385-398.

Ehrlén, K. (2009). Drawings as representations of children's conceptions. *International Journal of Science Education, 31*, 41-57. doi:10.1080/09500690701630455

Eilam, B., & Poyas, Y. (2008). Learning with multiple representations: Extending multimedia learning beyond the lab. *Learning and Instruction, 18*, 368-378.

Ericsson, K. A., & Simon, H. A. (1984). *Protocol analysis: Verbal reports as data.* Cambridge, MA: MIT Press.

Fang, Z. (2005). Scientific literacy: A systemic functional linguistics perspective. *Science Education, 89*, 335-347.

Fang, Z. (2006). The language demands of science reading in middle school. *International Journal of Science Education, 5*, 491-520.

Fang, Z., & Schleppegrell, M. J. (2010). Disciplinary literacies across content areas: Supporting secondary reading through functional language analysis. *Journal of Adolescent and Adult Literacy, 53*, 587-597. doi:10.1598/JAAL.53.7.6

Felton, P. (2008). Visual literacy. *Change, 40*(6), 60-63.

Fletcher, J. D., & Tobias, S. (2005). The multimedia principle. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 117-133). New York, NY: Cambridge University Press.

Flick, U. (2002). *An introduction to qualitative research* (2nd ed.). Thousand Oaks, CA: Sage.

Florax, M., & Ploetzner, R. (2009). What contributes to the split-attention effect? The role of text segmentation, picture labeling, and spatial proximity. *Learning and Instruction, 20*, 216-224. doi:10.1016/j.learninstruc.2009.02.021

Ford, C. L., & Yore, L. D. (in press). Toward convergence of critical thinking, metacognition, and reflection: Illustrations from natural and social sciences teacher education and classroom practice. In A. Zohar & Y. J. Dori (Eds.), *Metacognition in science education: Trends in current research* (pp. TBC). Dordrecht, The Netherlands: Springer.

Fry, E. (2002). Readability versus leveling. *The Reading Teacher, 56*(3), 286-291.

Garcia-Mila, M., Andersen, C., & Rojo, N. E. (2010). The development of scientific inquiry strategies and representational practices in preadolescents. In C. Andersen, N. Scheuer, M. P. Pérez Echeverría, & E. V. Teubal (Eds.), *Representational systems and practices as learning tools* (pp. 167-185). Boston, MA: Sense.

Gee, J. (2005). Language in the science classroom: Academic social languages as the heart of school-based literacy. In R. Yerrick & W-M. Roth (Eds.), *Establishing scientific classroom discourse communities: Multiple voices of teaching and learning research* (pp. 19-37). Mahwah, NJ: Lawrence Erlbaum.

Gerstner, S., & Bogner, F. X. (2009). Concept map structure, gender, and teaching methods: An investigation of students' science learning. *Educational Research, 51*, 425-438. doi:10.1080/00131880903354758

Gilbert, J. K. (2007). Visualization: A metacognitive skill in science and science education. In J. K. Gilbert (Ed.), *Visualization in science education* (pp. 9-27). Dordrecht, The Netherlands: Springer.

Gilbert, J. K. (2008). Visualization: An emergent field of practice and enquiry in science education. In J. K. Gilbert, M. Reiner, & M. Nakhleh (Eds.), *Visualization: Theory and practice in science education* (pp. 3-24). Dordrecht, The Netherlands: Springer.

Gilbert, J. K., Reiner, M., & Nakhleh, M. (2008). Introduction. In J. K. Gilbert, M. Reiner, & M. Nakhleh (Eds.), *Visualization: Theory and practice in science education* (pp. 1-2). Dordrecht, The Netherlands: Springer.

Greene, J. (2005). The generative potential of mixed methods inquiry. *International Journal of Research and Method in Education, 28*, 207-211.

Greenhalgh, T. (1997). How to read a paper: Papers that summarise other papers (systematic reviews and meta-analyses). *British Medical Journal, 315*, 672-675.

Gunel, M., Hand, B., & Gunduz, S. (2006). Comparing student understanding of quantum physics when embedding multimodal representations into two different writing formats: Presentation format versus summary report format. *Science Education, 90*, 1092-1112.

Habel, C., & Acartürk, C. (2007). On reciprocal improvement in multimodal generation: Co-reference by text and information graphics. In I. van der Sluis, M. Theune, E. Reiter, & E. Krahmer (Eds.), *MOG 2007, Proceedings of the Workshop on Multimodal Output Generation,* University of Aberdeen, United Kingdom.

Halliday, M. A. K. (2004). Three aspects of children's language development: Learning language, learning through language, and learning about language (1980). In J. Webster (Ed.), *The language of early childhood* (pp. 308-326). New York, NY: Continuum.

Halliday, M. A. K., & Martin, J. (1993). *Writing science: Literacy and discursive power*. London, England: Falmer.

Harrison, A. G., & Treagust, D. F. (2000). A typology of school science models. *International Journal of Science Education, 22*, 1011-1026.

Harskamp, E. G., Mayer, R. E., & Suhre, C. (2007). Does the modality principle for multimedia learning apply to science classrooms? *Learning and Instruction, 17*, 465-477. doi:10.1016/j.learninstruc.2007.09.010

Hays, P. A. (2004). Case study research. In K. deMarrais & S. D. Lapan (Eds.), *Foundations for research: Methods of inquiry in education and the social sciences* (pp. 217-234). Mahwah, NJ: Lawrence Erlbaum.

Hidrio, C. & Jamet, E. (2008). Learning from a multimedia explanation: A comparison of static pictures and animation. In J.-F. Rouet, R. Lowe, & W. Schnotz (Eds.), *Understanding multimedia documents* (pp. 103-118). doi:10.1007/978-0-387-73337-1_6

Horizon Research Inc. (2003). *Instruments*. Retrieved from http://www.horizon-research.com/instruments/lsc/cop.php

Horizon Research Inc. (2005). *2005–06 Local systemic change classroom observation protocol*. Retrieved from http://www.horizon-research.com/LSC/manual/0506/tab6/cop0506.pdf

Hubber, P., Tytler, R., & Haslam, F. (2010). Teaching and learning about force with a representational focus: Pedagogy and teacher change. *Research in Science Education, 40*, 5-28. doi:10.1007/s11165-009-9154-9

Hurd, P. D. (1958). Science literacy: Its meaning for American schools. *Educational Leadership, 16*(1), 13-16, 52.

Hurley, M. M. (1998). Science literacy: Lessons from the first generation. *Research Matters - to the Science Teacher*. No. 9801. Retrieved from http://www.narst.org/publications/research/Sciencel.cfm

Huxford, J. (2001). Visual images in the media. In N. J. Smelser & P. B. Baltes (Eds.), *International Encyclopedia of the Social and Behavioral Sciences*, pp. 16259-16264. doi:10.1016/B0-08-043076-7/04394-1

Hyönä, J. (2010). The use of eye movements in the study of multimedia learning. *Learning and Instruction, 20*, 172-176. doi:10.1016/j.learninstruc.2009.02.013

Iding, M. (2000). Can strategies facilitate learning from illustrated science texts? *International Journal of Instructional Media, 27*, 289-301.

International Visual Literacy Association. (2010). *What is "visual literacy"?* Retrieved from http://www.ivla.org/org_what_vis_lit.htm#definition

Isaac, S., & Michael, W. (1997). *Handbook in research and evaluation: A collection of principles, methods, and strategies useful in the planning, design, and evaluation of studies in education and the behavioral sciences* (3rd ed.). San Diego, CA: Educational and Industrial Testing Services.

Jewitt, C. (2008). Multimodality and literacy in school classrooms. *Review of Research in Education, 32*, 241-267.

Jewitt, C., Kress, G., Ogborn, J., & Tsatsarelis, C. (2001). Exploring learning through visual, actional and linguistic communication: The multimodal environment of a science classroom. *Educational Review, 53*, 5-18. doi:10.1080/0013191012003360 0

Johnson, B., & Turner, L., (2003). Data collection strategies in mixed methods research. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of mixed methods in social and behavioral research* (pp. 297-319). Thousand Oaks, CA: Sage.

Johnson, R. B., Onwuegbuzie, A., & Turner, L. (2007). Toward a definition of mixed methods research. *Journal of Mixed Methods Research, 1*, 112-133.

Keys, C. (1999). Revitalizing instruction in scientific genre: Connecting knowledge production with writing to learn in science. *Science Education, 83*, 115-130.

Kikas, E. (2006). The effect of verbal and visuo-spatial abilities on the development of knowledge of the Earth. *Research in Science Education, 36*, 269-283. doi:10.1007/s11165-005-9010-5

Kohl, P., & Finkelstein, N. (2005a). Student representational competence and self-assessment when solving physics problems. *Physical Review Special Topics - Physics Education Research*, *1*(1). doi: 10.1103/PhysRevSTPER.1.010104

Kohl, P., & Finkelstein, N. (2005b). Student representational competence and the role of instructional environment in introductory physics. *2005 Physics Education Research Conference Proceedings*, 93-96.

Kozma, R. (2003). The material features of multiple representations and their cognitive and social affordances for science understanding. *Learning and Instruction, 13*, 205-226. doi:10.1016/S0959-4752(02)00021-X

Kozma, R., & Russell, J. (2005a). Multimedia learning of chemistry. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 409-428). New York, NY: Cambridge University Press.

Kozma, R., & Russell, J. (2005b). Students becoming chemists: Developing representational competence. In J. K. Gilbert (Ed.), *Visualization in science education* (pp. 121-145). Dordrecht, The Netherlands: Springer.

Kress, G. (2010). *Multimodality: A social semiotic approach to contemporary communication*. New York, NY: Routledge.

Kress, G., & van Leeuwen, T. (2006). *Reading images: The grammar of visual design* (2nd ed.). New York, NY: Routledge.

Latour, B. (1988). Drawings things together. In M. Lynch & S. Woolgar (Eds.), *Representation in scientific practice* (pp. 19-68). Cambridge, MA: MIT Press.

Lemke, J. (1998). Multiplying meaning: Visual and verbal semiotics in scientific text. In J. R. Martin & R. Veel (Eds.), *Reading science: Critical and functional perspectives on discourses of science* (pp. 87-113). New York, NY: Routledge.

Lemke, J. (2003). *Teaching all the languages of science: Words, symbols, images, and actions*. Retrieved from http://www-personal.umich.edu/~jaylemke/papers

Leutner, D., Leopold, C., & Sumfleth, E. (2009). Cognitive load and science text comprehension: Effects of drawing and mentally imagining text content. *Computers in Human Behavior, 25*, 284-289. doi:10.1016/j.chb.2008.12.010

Levin, T., & Wagner, T. (2009). Mixed-methodology research in science education: Opportunities and challenges in exploring and enhancing thinking dispositions. In M. C. Shelley II, L. D. Yore, & B. Hand (Eds.), *Quality research in literacy and science education: International perspectives and gold standards* (pp. 213-243). Dordrecht, The Netherlands: Springer.

Lewalter, D. (2003). Cognitive strategies for learning from static and dynamic visuals. *Learning and Instruction, 13*, 177-189. doi:10.1016/S0959-4752(02)00019-1

Lewthwaite, B., & Fisher, D. (2005). The development and validation of a primary science curriculum delivery evaluation questionnaire. *International Journal of Science Education, 27*, 593-606. doi:10.1080/0950069042000230758

Liszka, J. J. (1996). *A general introduction to the semeiotic of Charles Sanders Peirce*. Bloomington, IN: Indiana University.

Low, R., & Sweller, J. (2005). The modality principle in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 147-158). New York, NY: Cambridge University Press.

Lowe, R. (2000). *Visual literacy and learning in science*. Retrieved from ERIC database. (ED463945)

Lynch, M. (2001). Visualization: Representation in science. In N. J. Smelser & P. B. Baltes (Eds.), *International Encyclopedia of the Social and Behavioral Sciences*, pp. 16288-16292. doi:10.1016/B0-08-043076-7/03181-8

Malter, M. (1947a). The ability of children to read a process-diagram. *Journal of Educational Psychology, 38*, 290-298.

Malter, M. (1947b). The ability of children to read cross-sections. *Journal of Educational Psychology, 38*, 157-166.

Malter, M. (1948a). The ability of children to read conventionalized diagrammatic symbols. *Journal of Educational Psychology, 39*, 27-34.

Malter, M. (1948b). Children's ability to read diagrammatic materials. *The Elementary School Journal, 49*, 98-102.

Mansour, N. (2007). Challenges to STS education: Implications for science teacher education. *Bulletin of Science, Technology and Society, 27*, 482-497.

Manz, S. L. (2002). A strategy for previewing textbooks: Teaching readers to become THIEVES. *The Reading Teacher*, *55*, 434–435.

Márquez, C., Izquierdo, M., & Espinet, M. (2006). Multimodal science teachers' discourse in modeling the water cycle. *Science Education, 90*, 202-226.

Martins, I. (2002). Visual imagery in school science texts. In J. Otero, J. León, & A. Graesser (Eds.), *The psychology of science text comprehension* (pp. 73-90). Mahwah, NJ: Lawrence Erlbaum.

Mayer, R. E. (2001). *Multimedia learning*. New York, NY: Cambridge University Press.

Mayer, R. E. (2005a). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 31-48). New York, NY: Cambridge University Press.

Mayer, R. E. (2005b). Introduction to multimedia learning. In R. E. Mayer (Ed.), The Cambridge handbook of multimedia learning (pp. 1-16). New York, NY: Cambridge University Press.

Mayer, R. E. (2005c). Principles for reducing extraneous processing in multimedia learning: Coherence, signaling, redundancy, spatial contiguity, and temporal contiguity principles. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 183-200). New York, NY: Cambridge University Press.

Mayer, R. E., Bove, W., Bryman, A., Mars, R., & Tapangco, L. (1996). When less is more: Meaningful learning from visual and verbal summaries of science textbook lessons. *Journal of Educational Psychology, 88*(1), 64-73.

Mayer, R. E., Hegarty, M., Mayer, S., & Campbell, J. (2005). When static media promote active learning: Annotated illustrations versus narrated animations in multimedia instruction. *Journal of Experimental Psychology: Applied, 11*, 256-265. doi:10.1037/1076-898X.11.4.256

McComas, W. (1996). Ten myths of science: Reexamining what we think we know about the nature of science. *School Science and Mathematics, 96*, 10-16.

McCrudden, M., Schraw, G., & Lehman, S. (2007). The use of adjunct displays to facilitate comprehension of causal relationships in expository text. *Instructional Science, 37*, 65-86. doi: 10.1007/s11251-007-9036-3

McCrudden, M., Schraw, G., Lehman, S., & Poliquin, A. (2007). The effect of causal diagrams on text learning. *Contemporary Educational Psychology, 32*, 367-388. doi:10.1016/j.cedpsych.2005.11.002

McDermott, M. A., Hand, B., & Cavagnetto, A. R. (2010, March). *Exploring the impact of embedding multiple modes of representing science information in varied classroom settings*. Paper presented at the annual international conference of the National Association for Research in Science Teaching, Philadelphia, PA.

McGee, L. M. (1982). Awareness of text structure: Effects on children's recall of expository text. *Reading Research Quarterly, 17*, 581-590.

McGraw-Hill Ryerson. (2004). *BC Science 7*. Toronto, ON, Canada: Author.

McGraw-Hill Ryerson. (2005). *BC Science 6*. Toronto, ON, Canada: Author.

McGraw-Hill Ryerson. (2006). *BC Science 8*. Toronto, ON, Canada: Author.

Millar, R. (2006). Twenty-first century science: Insights from the design and implementation of a scientific literacy approach in school science. *International Journal of Science Education, 28*, 1499-1521.

Miller, G. A. (1994). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 101*, 343-352.

Ministry of Education, Province of British Columbia. (2005). *Science K to 7: Integrated resource package 2005*. Retrieved from http://www.bced.gov.bc.ca/irp/irp_sci.htm.

Ministry of Education, Province of British Columbia. (2006a). *English language arts Kindergarten to Grade 7: Integrated resource package 2006.* Retrieved from http://www.bced.gov.bc.ca/irp/ela_k7_2006.pdf

Ministry of Education, Province of British Columbia. (2006b). *Science 8: Integrated resource package 2006*. Retrieved from http://www.bced.gov.bc.ca/irp/irp_sci.htm

Ministry of Education, Province of British Columbia. (2009). *BC performance standards*. Retrieved from http://www.bced.gov.bc.ca/perf_stands/writing_g6.pdf

Moje, E. B. (2008). Foregrounding the disciplines in secondary literacy teaching and learning: A call for change. *Journal of Adolescent and Adult Literacy, 52*, 96-107.

Moje, E. B., Collazo, T., Carrillo, R., & Marx, R. W. (2001). "Maestro, what is quality?" Language, literacy, and discourse in project-based science. *Journal of Research in Science Teaching, 38*, 469-496.

Moline, S. (1995). *I see what you mean: Children at work with visual information.* Markham, ON, Canada: Pembroke.

Moreno, R. & Mayer, R. E. (2002). Verbal redundancy in multimedia learning: When reading helps listening. *Journal of Educational Psychology*, 94, 156-163.

Moreno, R., & Valdez, A. (2005). Cognitive load and learning effects of having students organize pictures and words in multimedia environments: The role of student interactivity and feedback. *Educational Technology Research & Development*, *53*(3), 35-45.

Mortimer, E. F., & Buty, C. (2010). What does "in the infinite" mean? In C. Andersen, N. Scheuer, M. P. Pérez Echeverría, & E. V. Teubal (Eds.), *Representational systems and practices as learning tools* (pp. 225-242). Boston, MA: Sense.

Muller, D., Sharma, M., & Reimann, P. (2008). Raising cognitive load with linear multimedia to promote conceptual change. *Science Education, 92*, 278-296.

Myers, G. (1988). Every picture tells a story: Illustrations in E.O. Wilson's *Sociobiology*. In M. Lynch & S. Woolgar (Eds.), *Representation in scientific practice* (pp. 231-299). Cambridge, MA: MIT Press.

Myers, M. (1996). *Changing our minds: Negotiating English and literacy*. Urbana, IL: National Council of Teachers of English.

National Geographic School Publishing. (2008). *Science theme sets: Differentiated instruction at its best*. Retrieved from http://www.ngsp.com/Products/Science/nbspnbspThemeSets/tabid/577/Default.aspx

Nelson Publishing. (2005a). *BC Science Probe 6*. Toronto, ON, Canada: Author.

Nelson Publishing. (2005b). *BC Science Probe 7*. Toronto, ON, Canada: Author.

Nelson Publishing. (2006). *BC Science Probe 8*. Toronto, ON, Canada: Author.

New London Group. (1996). A pedagogy of multiliteracies: Designing social futures. *Harvard Educational Review, 66*(1), 60-92.

Nieswandt, M., & McEneaney, E. H. (2009). Approaching classroom realities: The use of mixed methods and structural equation modeling in science education research. In M. C. Shelley II, L. D. Yore, & B. Hand (Eds.), *Quality research in literacy and science education: International perspectives and gold standards* (pp. 189-211). Dordrecht, The Netherlands: Springer.

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education, 87*(2), 224-240.

Novick, L. R. (2006). The importance of both diagrammatic conventions and domain-specific knowledge for diagram literacy in science: The hierarchy as an illustrative case. In D. Barker-Plummer, R. Cox, & N. Swoboda (Eds.), *Diagrammatic representation and inference* (pp. 1-11). Berlin, NY: Springer.

Paivio, A. (1991). *Images in mind: The evolution of a theory*. New York, NY: Harvester Wheatsheaf.

Pappas, C. C., & Varelas, M. (2009). Multimodal books in science-literacy units: Language and visual images for making meaning. *Language Arts, 86*, 201-211.

Pazzaglia, F. (2008). Text and picture integration in comprehending and memorizing spatial descriptions. In J.-F. Rouet, R. Lowe, & W. Schnotz (Eds.), *Understanding multimedia documents* (pp. 43-59). doi:10.1007/978-0-387-73337-1_3

Peirce, C. S. (1955). *Philosophical writings of Peirce, selected and edited with an introduction by Justus Buchler*. New York, NY: Dover. (Original work published 1940 as *The philosophy of Peirce: Selected writings*)

Peirce, C. S. (1986a). On representations. In C. J. W. Kloesel (Ed.), *The writings of Charles S. Peirce: A chronological edition* (Vol. 3, 1872-1878, pp. 62-65). Bloomington, IN: Indiana University.

Peirce, C. S. (1986b). On signs. In C. J. W. Kloesel (Ed.), *The writings of Charles S. Peirce: A chronological edition* (Vol. 3, 1872-1878, pp. 66-68). Bloomington, IN: Indiana University.

Pérez Echeverría, M. P., Postigo, Y., & Pecharroman, A. (2010). Graphicacy: University students' skills in translating information. In C. Andersen, N. Scheuer, M. P. Pérez Echeverría, & E. V. Teubal (Eds.), *Representational systems and practices as learning tools* (pp. 209-224). Boston, MA: Sense.

Pérez Echeverría, M. P., & Scheuer, N. (2010). External representations as learning tools: An introduction. In C. Andersen, N. Scheuer, M. P. Pérez Echeverría, & E. V. Teubal (Eds.), *Representational systems and practices as learning tools* (pp. 1-17). Boston, MA: Sense.

Piaget, J. (1977). *The development of thought* (A. Rosin, Trans.). New York, NY: Viking. (Original work published 1975)

Pintó, R., & Ametller, J. (2002). Students' difficulties in reading images. Comparing results from four national research groups. *International Journal of Science Education, 24*, 333-341. doi:10.1080/09500690110078932

Polkinghorne, D. E. (2005). Language and meaning: Data collection in qualitative research. *Journal of Counseling Psychology, 52*(2), 137-145.

Prain, V., & Waldrip, B. (2006). An exploratory study of teachers' and students' use of multi-modal representations of concepts in primary science. *International Journal of Science Education, 28*, 1843-1866.

Rasch, T., & Schnotz, W. (2009). Interactive and non-interactive pictures in multimedia learning environments: Effects on learning outcomes and learning efficiency. *Learning and Instruction, 19*, 411-422. doi:10.1016/j.learninstruc.2009.02.008

Reiss, M. J., Boulter, C., & Tunnicliffe, S. D. (2007). Seeing the natural world: A tension between pupils' diverse conceptions as revealed by their visual representations and monolithic science lessons. *Visual Communication, 6*, 99-114.

Reiss, M. J., Tunnicliffe, S. D., Anderson, A. M., Bartoszeck, A., Carvalho, G. S., & Chen, S-Y., ... Van Roy, W. (2002). An international study of young peoples' drawings of what is inside themselves. *Journal of Biological Education, 36*(2), 58-64.

Richard, C. (2002). The fundamental design variables of diagramming. In M. Anderson, B. Meyer, & P. Olivier (Eds.), *Diagrammatic representation and reasoning* (pp. 85-102). London, England: Springer.

Rozenblit, L., Spivey, M., & Wojslawowicz, J. (2002). Mechanical reasoning about gear-and-belt diagrams: Do eye-movements predict performance? In M. Anderson, B. Meyer, & P. Olivier (Eds.), *Diagrammatic representation and reasoning* (pp. 223-240). London, England: Springer.

Rundgren, C.-J., & Tibell, L. (2009). Critical features of visualizations of transport through the cell membrane - An empirical study of upper secondary and tertiary students' meaning-making of a still image and an animation. *International Journal of Science and Mathematics Education, 8*, 223-246. doi:10.1007/s10763-009-9171-1

Sadoski, M., & Paivio, A. (2001). *Imagery and text: A dual coding theory of reading and writing*. Mahwah, NJ: Lawrence Erlbaum.

Schmidt-Weigand, F., Kohnert, A., & Glowalla, U. (2010). A closer look at split visual attention in system- and self-paced instruction in multimedia learning. *Learning and Instruction, 20*, 100-110. doi:10.1016/j.learninstruc.2009.02.011

Schnotz, W. (2002). Towards an integrated view of learning from text and visual displays. *Educational Psychology Review, 14*(1), 101-120.

Schnotz, W. (2005). An integrated model of text and picture comprehension. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 49-69). New York, NY: Cambridge University Press.

Schnotz, W., & Bannert, M. (2003). Construction and interference in learning from multiple representations. *Learning and Instruction, 13*, 141-156. doi:10.1016/S0959-4752(02)00017-8

Schnotz, W., & Kürschner, C. (2008). External and internal representations in the acquisition and use of knowledge: Visualization effects on mental model construction. *Instructional Science, 36*, 175-190. doi:10.1007/s11251-007-9029-2

Seufert, T. (2003). Supporting coherence formation in learning from multiple representations. *Learning and Instruction, 13*, 227-237. doi:10.1016/S0959-4752(02)00022-1

Shanahan, T., & Shanahan, C. (2008). Teaching disciplinary literacy to adolescents: Rethinking content-area literacy. *Harvard Educational Review, 78*, 40-59.

Shen, B. (1975). Science literacy: The public need. *The Sciences, 15*(1), 27-28.

Shepardson, D. P., & Britsch, S. J. (2001). Tools for assessing and teaching science in elementary and middle school. In D. P. Shepardson (Ed.), *Assessment in science: A guide to professional development and classroom practice* (pp. 119-147). Dordrecht, The Netherlands: Kluwer.

Siegel, M. (1995). More than words: The generative power of transmediation for learning. *Canadian Journal of Education, 20*(4), 455-475.

Smolkin, C. A., & Donovan, L. B. (2002). Considering genre, content, and visual features in the selection of trade books for science instruction. *The Reading Teacher, 55*, 502-520.

Snow, C. E. (2010). Academic language and the challenge of reading for learning about science. *Science*, *328*, 50-452.

Stake, R. E. (2010). *Qualitative research: Studying how things work*. New York, NY: Guilford.

Stylianidou, F., Ormerod, F., & Ogburn, J. (2002). Analysis of science textbook pictures about energy and pupils' readings of them. *International Journal of Science Education, 24*, 257-283.

Sweller, J. (2005). The redundancy principle in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 159-167). New York, NY: Cambridge University Press.

Sweller, J., & Chandler, P. (1991). Evidence for cognitive load theory. *Cognition and Instruction, 8*, 351-362.

SYSTAT Software Inc. (2007). *MYSTAT 12* [software]. Available at http://www.systat.com/MystatProducts.aspx

Tang., K-S., & Moje, E. B. (2010). Relating multimodal representations to the literacies of science. *Research in Science Education, 40*, 81-85. doi:10.1007/s11165-009-9158-5

Tashakkori, A., & Creswell, J. (2007). Exploring the nature of research questions in mixed methods research. *Journal of Mixed Methods Research, 1*, 207-211.

Tashakkori, A., & Teddlie, C. (1998). *Mixed methodology: Combining qualitative and quantitative approaches*. Thousand Oaks, CA: Sage.

Tashakkori, A., & Teddlie, C. (2003). The past and future of mixed methods research from data triangulation to mixed model designs. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of mixed methods in social and behavioral research* (pp. 671-701). Thousand Oaks, CA: Sage.

Teddlie, C., & Tashakkori, A. (2003). Major issues and controversies in the use of mixed methods in the social and behavioral sciences. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of mixed methods in social and behavioral research* (pp. 3-50). Thousand Oaks, CA: Sage.

Tippett, C. D., & Yore, L. D. (2009a, September). *Middle school students use posters, brochures, and Foldables® to demonstrate understanding of science concepts*. Poster presented at the 7th biennial conference of the European Science Education Research Association, Istanbul, Turkey.

Tippett, C. D., & Yore, L. D. (2009b, September). *The development of an integrated framework*. Paper presented at the 7th biennial conference of the European Science Education Research Association, Istanbul, Turkey.

Tippett, C. D., & Yore, L. D. (2010, March). *The impact of professional development: Teaching an enhanced multimodal grade 6 science unit on extreme environments*. Paper presented at the annual international conference of the National Association for Research in Science Teaching, Philadelphia, PA.

Tippett, C. D., Yore, L. D., & Anthony, R. J. (2008, June). *Creating brochures: An authentic writing task for representing understanding in middle school science*. Paper presented at the 9th Nordic Research Symposium on Science Education, Reykjavik, Iceland.

Tomatosphere. (2010). *Teachers' guide*. Available at http://www.tomatosphere.org/teacher-resources/teachers-guide/

Tomlinson, C. A. (2000). *Differentiation of instruction in the elementary grades*. Retrieved from ERIC database. (ED443572)

Tompkins, G., Bright, R., Pollard, M., & Winsor, P. (2008). *Language arts: Content and teaching strategies* (4th Canadian ed.). Toronto, ON, Canada: Pearson Prentice Hall.

Treagust, D. F. (2007). General instructional methods and strategies. In S. Abell & N. Lederman (Eds.), *Handbook of research on science education* (pp. 373-391). Mahwah, NJ: Lawrence Erlbaum.

Trumbo, J. (1999). Visual literacy and science communication. *Science Communication, 20*, 409-425.

Trumbo, J. (2000). Essay: Seeing science. *Science Communication, 21*, 379-391.

Turner, J. C., & Meyer, D. K. (2000). Studying and understanding the instructional contexts of classrooms: Using our past to forge our future. *Educational Psychologist, 35*(2), 69-85. doi:10.1207/S15326985EP3502_2

Tytler, R., Peterson, S., & Prain, V. (2006). Picturing evaporation: Learning science literacy through a particle representation. *Teaching Science, 52*, 12-17.

Tytler, R., Prain, V., & Peterson, S. (2007). Representational issues in students learning about evaporation. *Research in Science Education, 37*, 313-331.

United States National Research Council. (1996). *The national science education standards.* Washington, DC: The National Academies Press.

United States National Research Council. (2005). *How students learn: Science in the classroom*. Committee on How people learn, A Targeted Report for Teachers. M. S. Donovan & J. D. Bransford (Eds.). Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Unsworth, L. (2001). *Teaching multiliteracies across the curriculum: Changing contexts of text and image in classroom practice*. Philadelphia, PA: Open University Press.

Unsworth, L. (2004). Comparing school science explanations in books and computer-based formats: The role of images, image/text relations and hyperlinks. *International Journal of Instructional Media, 31*, 283-301.

Van der Flier-Keller, E., Anthony, R. J., Tippett, C. D., & Stege, U. (2010, January). *The outcomes of large-scale professional development in science education: Pacific CRYSTAL.* Paper presented at the annual international conference of the Association for Science Teacher Education, Sacramento, CA.

van Gog, T., Kester, L., Nievelstein, F., Giesbers, B., & Paas, F. (2009). Uncovering cognitive processes: Different techniques that can contribute to cognitive load research and instruction. *Computers in Human Behavior, 25*, 325-331. doi:10.1016/j.chb.2008.12.021

Van Meter, P. (2001). Drawing construction as a strategy for learning from text. *Journal of Educational Psychology, 93*, 129-140. doi:10.1037//0022-0663.93.1.129

Van Meter, P., Aleksic, M., Schwartz, A., & Garner, J. (2006). Learner-generated drawing as a strategy for learning from content area text. *Contemporary Educational Psychology, 31*, 142-166.

van Someren, M. W., Boshuizen, H. P. A., de Jong, T., & Reimann, P. (1998). Introduction. In M. W. van Someren, P. Reimann, H. P. A. Boshuizen, & T. de Jong (Eds.), *Learning with multiple representations* (pp. 1-5). New York, NY: Elsevier Science.

Veel, R. (1998). The greening of school science: Ecogenesis in secondary classrooms. In J. R. Martin & R. Veel (Eds.), *Reading science: Critical and functional perspectives on discourses of science* (pp. 114-151). New York, NY: Routledge.

Verdi, M. P., & Kulhavy, R. W. (2002). Learning with maps and texts: An overview. *Educational Psychology Review*, 14(1), 27-46.

Vygotsky, L. S. (1934/1986). *Thought and language* (A. Kozulin, Trans.). Cambridge, MA: MIT Press.

Waldrip, B., & Prain, V. (2006). Changing representations to learn primary science concepts. *Journal of the Australian Science Teachers Association, 52*(4), 17-21.

Waldrip, B., Prain, V., & Carolan, J. (2010). Using multi-modal representations to improve learning in junior secondary science. *Research in Science Education, 40*, 65-80. doi:10.1007/s11165-009-9157-6

Westby, C., & Torres-Valasquez, D. (2000). Developing scientific literacy: A sociocultural approach. *Remedial & Special Education, 21*, 101-110.

Wiebe, E., & Annetta, L. (2008). Influences on visual attentional distribution in multimedia instruction. *Journal of Educational Multimedia and Hypermedia, 17*, 259-277.

Wilder, A., & Brinkerhoff, J. (2007). Supporting representational competence in high school biology with computer-based biomolecular visualizations. *Journal of Computers in Mathematics and Science Teaching, 26*(1), 5-26.

Willinsky, J. (1990). *The new literacy: Redefining reading and writing in the schools*. New York, NY: Routledge.

Winn, B. (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.

Wittrock, M. C. (2010). Learning as a generative process. *Educational Psychologist, 45*, 40–55. doi:10.1080/00461520903433554 (Reprinted from *Educational Psychologist*, 11, 87-97)

Yin, R. K. (2009). *Case study research: Design and methods*. Thousand Oaks, CA: Sage.

Yore, L. D. (2001). What is meant by constructivist science teaching and will the science education community stay the course for meaningful reform? *Electronic Journal of Science Education, 5*(4). Retrieved from http://wolfweb.unr.edu/homepage/crowther/ejse/yore.html

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., Florence, M. K., Pearson, T. W., & Weaver, A. J. (2006). Written discourse in scientific communities: A conversation with two scientists about their views of science, use of language, role of writing in doing science, and compatibility between their epistemic views and language. *International Journal of Science Education, 28*(2/3), 109-141. doi:10.1080/09500690500336601

Yore, L. D., & Hand, B. M. (2010). Epilogue: Plotting a research agenda for multiple representations, multiple modality, and multimodal representational competency. *Research in Science Education, 40*(1)*,* 93-101. doi:10.1007/s11165-009-9160-y

Yore, L. D., Hand, B. M., & Florence, M. K. (2004). Scientists' views of science, models of writing, and science writing practices. *Journal of Research in Science Teaching, 41*(4)*,* 338-369.

Yore, L. D., Pimm, D., & Tuan, H-L. (2007). The literacy component of mathematical and scientific literacy. *International Journal of Science and Mathematics, 5*(4), 559-589.

Yore, L. D., & Rossman, G. B. (2010). Case-to-case synthesis. In A. J. Mills, G. Durepos, & E. Wiebe (Eds.), *Encyclopedia of case study research* (Vol. 1, pp. 129-134). Thousand Oaks, CA: Sage.

Yore, L. D., & Treagust, D. F. (2006). Current realities and future possibilities: Language and science literacy – empowering research and informing instruction. *International Journal of Science Education, 28*(2/3), 291-314.

Zike, D. (2001). *Dinah Zike's big book of science for middle school and high school*. San Antonio, TX: Dinah-Might Adventures.

Zimmerman, D. W., & Zumbo, B. D. (2009). Hazards in choosing between pooled and separate-variances *t* tests. *Psicológica, 30*, 371-390. Retrieved from http://www.uv.es/revispsi/articulos2.09/12ZIMMERMAN.pdf

Appendices

Appendix A

Results of a Thematic Analysis of the Visual Representation Literature

The following tables show three different aspects of a thematic analysis of recent studies of representations in science. In Table A1, the books that I manually searched are listed in alphabetical order. In Table A2, the themes revealed by the analysis of 52 studies are listed in order of occurrence, along with the ID number of the studies in which that theme was evident. In Table A3, the 52 studies are listed in alphabetical order, along with their ID numbers and up to three themes.

Table A1

Books Manually Searched for Recent Studies of Diagram Use in Science

Andersen, C., Scheuer, N., Pérez Echeverría, M. P., & Teubal, E. V. (Eds.). (2010). *Representational systems and practices as learning tools*. Boston, MA: Sense Publishers.
Anderson, M., Meyer, B., & Olivier, P. (Eds.). (2002). *Diagrammatic representation and reasoning*. London, UK: Springer.
Clement, J. J. (Ed). (2008). *Creative model construction in scientists and students: The role of imagery, analogy, and mental simulation*. Dordrecht, The Netherlands: Springer.
Gilbert, J. K. (Ed.). (2007). *Visualization in science education*. Dordrecht, The Netherlands: Springer.
Gilbert, J. K., De Jong, O., Justi, R., Treagust, D. F., & Van Driel, J. H. (Eds.). (2002). Chemical education: Towards research-based practice. Dordrecht, The Netherlands: Kluwer Academic.
Gilbert, J. K., Reiner, M., & Nakhleh, M. (Eds.). (2008). *Visualization: Theory and practice in science education*. New York, NY: Springer.
Otero, J., León, J., & Graesser, A. (Eds.). (2002). *The psychology of science text comprehension*. Mahwah, NJ: Lawrence Erlbaum.
Rouet, J.-F., Lowe, R., & Schnotz, W. (Eds.). (2008). *Understanding multimedia documents*. doi:10.1007/978-0-387-73337-1_4

Table A2

Common Themes in Recent Studies of Diagram Use in Science

Theme		Study ID numbers
A	Learner-generated	1, 2, 3, 6, 9, 17, 22, 26, 32, 33, 38, 39, 47, 48, 49, 50, 51
B	Learning from visuals	4, 5, 11, 14, 19, 22, 29, 30, 32, 35, 43, 46
C	Student agency	1, 10, 17, 21, 36, 38, 39, 47, 48, 51
D	Classroom-based	10, 21, 22, 32, 33, 36, 47, 48, 50
E	Assessment opportunities	1, 2, 6, 10, 17, 33, 38, 39
F	Representational competence	9, 12, 13, 16, 24, 25, 51
G	Static versus dynamic	20, 27, 28, 37, 41, 52
H	Cognitive load	7, 26, 31, 34, 52
I	Strategies for learning	4, 11, 27, 31, 45
J	Prior knowledge	11, 15, 45
K	Multimedia principles	18, 19, 42
L	Visual spatial ability	3, 23, 34
M	Internal versus external	8, 26, 44
N	Eye-tracking	18, 38, 52
O	Memory	20, 34

Table A3

Recent Studies of Diagram Use in Science

Themes	ID	Citation
A, C, E	1	Acher, A., & Arcà, M. (2010). Children's representations in modeling scientific knowledge construction. In C. Andersen, N. Scheuer, M. P. Pérez Echeverría, & E. V. Teubal (Eds.), *Representational systems and practices as learning tools* (pp. 109-131). Boston, MA: Sense.
A, E	2	Adadan, E., Irving, K. E., & Trundle, K. C. (2009). Impacts of multi-representational instruction on high school students' conceptual understandings of the particulate nature of matter. *International Journal of Science Education, 31*, 1743-1775. doi:10.1080/09500690802178628
A, L	3	Ainsworth, S., Galpin, J., & Musgrove, S. (2007, September). *Learning about dynamic systems by drawing for yourself and for others*. Paper presented at the 6th biennial conference of the European Science Education Research Association, Budapest, Hungary.
B, I	4	Ainsworth, S., & Loizou, A. (2003). The effects of self-explaining when learning with text or diagrams. *Cognitive Science, 27*, 669-681. doi:10.1207/s15516709cog2704_5
B	5	Ametller, J., & Pintó, R. (2002). Students' reading of innovative images of energy at secondary school level. *International Journal of Science Education, 24*, 285-312. doi:10.1080/09500690110078914

Themes	ID	Citation
A, E	6	Best, R., Dockrell, J., & Braisby, N. (2010). Children's semantic representations of a science term. In C. Andersen, N. Scheuer, M. P. Pérez Echeverría, & E. V. Teubal (Eds.), *Representational systems and practices as learning tools* (pp. 93-108). Boston, MA: Sense.
H	7	Betrancourt, M., Dilenbourg, P., & Clavien, L. (2008). Display of key pictures from animation: Effects on learning. In J.-F. Rouet, R. Lowe, & W. Schnotz (Eds.), *Understanding multimedia documents* (pp. 61-78). New York, NY: Springer. doi:10.1007/978-0-387-73337-1_4
M	8	Bodemer, D., & Faust, U. (2006). External and mental referencing of multiple representations. *Computers in Human Behavior, 22*, 27-42. doi:10.1016/j.chb.2005.01.00
A, F	9	Botzer, G. & Reiner, M. (2007). Imagery in physics learning - from physicists' practice to naïve students' understanding. In J. K. Gilbert (Ed.), *Visualization in science education* (pp. 147-168). Dordrecht, The Netherlands: Springer.
C, D, E	10	Brooks, M. (2009). Drawing, visualisation and young children's exploration of "big ideas". *International Journal of Science Education, 31*, 319-341. doi:10-1080/09500690802595771
B, J, I	11	Butcher, K. (2006). Learning from text with diagrams: Promoting mental model development and inference generation. *Journal of Educational Psychology, 98*, 182-197.
F	12	Chandrasegaran, A. L., Treagust, D. F., & Mocerino, M. (2008). An evaluation of a teaching intervention to promote students' ability to use multiple levels of representation when describing and explaining chemical reactions. *Research in Science Education, 38*, 237-248.
F	13	Chittleborough, G., & Treagust, D. F. (2008). Correct interpretation of chemical diagrams requires transforming from one level of representation to another. *Research in Science Education*, 38, 463-482.
B	14	Colin, P., Chauvet, F., & Viennot, L. (2002). Reading images in optics: Students' difficulties and teachers' views. *International Journal of Science Education, 24*, 313-332. doi:10.1080/09500690110078923
J	15	Cook, M., Carter, G., & Wiebe, E. (2008). The interpretation of cellular transport graphics by students with low and high prior knowledge. *International Journal of Science Education, 30*, 239-261. doi:10.1080/09500690601187168
F	16	diSessa, A., & Sherin, B. (2000). Metarepresentation: An introduction. *The Journal of Mathematical Behavior, 19*, 385-398.
A, C, E	17	Ehrlén, K. (2009). Drawings as representations of children's conceptions. *International Journal of Science Education, 31*, 41-57. doi:10.1080/09500690701630455
K, N	18	Florax, M., & Ploetzner, R. (2009). What contributes to the split-attention effect? The role of text segmentation, picture labeling, and spatial proximity. *Learning and Instruction, 20*, 216-224. doi:10.1016/j.learninstruc.2009.02.021
B, K	19	Harskamp, E. G., Mayer, R. E., & Suhre, C. (2007). Does the modality principle for multimedia learning apply to science classrooms? *Learning and Instruction, 17*, 465-477. doi:10.1016/j.learninstruc.2007.09.010

Themes	ID	Citation
G, O	20	Hidrio, C. & Jamet, E. (2008). Learning from a multimedia explanation: A comparison of static pictures and animation. In J.-F. Rouet, R. Lowe, & W. Schnotz (Eds.), *Understanding multimedia documents* (pp. 103-118). New York, NY: Springer. doi:10.1007/978-0-387-73337-1_6
C, D	21	Hubber, P., Tytler, R., & Haslam, F. (2010). Teaching and learning about force with a representational focus: Pedagogy and teacher change. *Research in Science Education, 40*, 5-28. doi:10.1007/s11165-009-9154-9
A, B, D	22	Jewitt, C., Kress, G., Ogborn, J., & Tsatsarelis, C. (2001). Exploring learning through visual, actional and linguistic communication: The multimodal environment of a science classroom. *Educational Review, 53*, 5-18. doi:10.1080/0013191012003360 0
L	23	Kikas, E. (2006). The effect of verbal and visuo-spatial abilities on the development of knowledge of the Earth. *Research in Science Education, 36*, 269-283. doi:10.1007/s11165-005-9010-5
F	24	Kohl, P., & Finkelstein, N. (2005a). Student representational competence and self-assessment when solving physics problems. *Physical Review Special Topics - Physics Education Research*, *1*(1). doi:10.1103/PhysRevSTPER.1.010104
F	25	Kohl, P., & Finkelstein, N. (2005b). Student representational competence and the role of instructional environment in introductory physics. *2005 Physics Education Research Conference Proceedings*, 93-96.
A, H, M	26	Leutner, D., Leopold, C. & Sumfleth, E. (2009). Cognitive load and science text comprehension: Effects of drawing and mentally imagining text content. *Computers in Human Behavior, 25*, 284-289. doi:10.1016/j.chb.2008.12.010
G, I	27	Lewalter, D. (2003). Cognitive strategies for learning from static and dynamic visuals. *Learning and Instruction, 13*, 177-189. doi:10.1016/S0959-4752(02)00019-1
G	28	Mayer, R. E., Hegarty, M., Mayer, S., & Campbell, J. (2005). When static media promote active learning: Annotated illustrations versus narrated animations in multimedia instruction. *Journal of Experimental Psychology: Applied, 11*, 256-265. doi:10.1037/1076-898X.11.4.256
B	29	McCrudden, M., Schraw, G., & Lehman, S. (2007). The use of adjunct displays to facilitate comprehension of causal relationships in expository text. *Instructional Science, 37*, 65-86. doi:10.1007/s11251-007-9036-3
B	30	McCrudden, M., Schraw, G., Lehman, S., & Poliquin, A. (2007). The effect of causal diagrams on text learning. *Contemporary Educational Psychology, 32*, 367-388. doi:10.1016/j.cedpsych.2005.11.002
H, I	31	Moreno, R., & Valdez, A. (2005). Cognitive load and learning effects of having students organize pictures and words in multimedia environments: The role of student interactivity and feedback. *Educational Technology Research & Development*, *53*(3), 35-45.
A, B, D	32	Mortimer, E. F., & Buty, C. (2010). What does “in the infinite” mean? In C. Andersen, N. Scheuer, M. P. Pérez Echeverría, & E. V. Teubal (Eds.), *Representational systems and practices as learning tools* (pp. 225-242). Boston, MA: Sense.
A, D, E	33	Pappas, C. C., & Varelas, M. (2009). Multimodal books in science-literacy units: Language and visual images for making meaning. *Language Arts, 86*, 201-211.

Themes	ID	Citation
H, L, O	34	Pazzaglia, F. (2008). Text and picture integration in comprehending and memorizing spatial descriptions. In J.-F. Rouet, R. Lowe, & W. Schnotz (Eds.), *Understanding multimedia documents* (pp. 43-59). New York, NY: Springer. doi:10.1007/978-0-387-73337-1_3
B	35	Pintó, R., & Ametller, J. (2002). Students' difficulties in reading images. Comparing results from four national research groups. *International Journal of Science Education, 24*, 333-341. doi:10.1080/09500690110078932
A, C, D	36	Prain, V., & Waldrip, B. (2006). An exploratory study of teachers' and students' use of multi-modal representations of concepts in primary science. *International Journal of Science Education, 28*, 1843-1866.
G	37	Rasch, T., & Schnotz, W. (2009). Interactive and non-interactive pictures in multimedia learning environments: Effects on learning outcomes and learning efficiency. Learning and Instruction, 19, 411-422. doi:10.1016/j.learninstruc.2009.02.008
A, C, E	38	Reiss, M., Boulter, C., & Tunnicliffe, S. (2007). Seeing the natural world: A tension between pupils' diverse conceptions as revealed by their visual representations and monolithic science lessons. *Visual Communication, 6*, 99-114.
A, C, E	39	Reiss, M., Tunnicliffe, S., Anderson, A., Bartoszeck, A., Carvalho, G., & Chen, S., et al. (2002). An international study of young peoples' drawings of what is inside themselves. *Journal of Biological Education, 36*(2), 58-64.
N	40	Rozenblit, L., Spivey, M., & Wojslawowicz, J. (2002). Mechanical reasoning about gear-and-belt diagrams: Do eye-movements predict performance? In M. Anderson, B. Meyer, & P. Olivier (Eds.), *Diagrammatic representation and reasoning* (pp. 223-240). London, England: Springer.
G	41	Rundgren, C.-J., & Tibell, L. (2009). Critical features of visualizations of transport through the cell membrane - An empirical study of upper secondary and tertiary students' meaning-making of a still image and an animation. *International Journal of Science and Mathematics Education, 8*, 223-246. doi:10.1007/s10763-009-9171-1
K	42	Schmidt-Weigand, F., Kohnert, A., & Glowalla, U. (2010). A closer look at split visual attention in system- and self-paced instruction in multimedia learning. Learning and Instrction, 20, 100-110. doi:10.1016/j.learninstruc.2009.02.011
B	43	Schnotz, W., & Bannert, M. (2003). Construction and interference in learning from multiple representations. *Learning and Instruction, 13*, 141-156. doi:10.1016/S0959-4752(02)00017-8
M	44	Schnotz, W., & Kürschner, C. (2008). External and internal representations in the acquisition and use of knowledge: Visualization effects on mental model construction. *Instructional Science, 36*, 175-190. doi:10.1007/s11251-007-9029-2
I, J	45	Seufert, T. (2003). Supporting coherence formation in learning from multiple representations. *Learning and Instruction, 13*, 227-237. doi:10.1016/S0959-4752(02)00022-1
B	46	Stylianidou, F., Ormerod, F., & Ogburn, J. (2002). Analysis of science textbook pictures about energy and pupils' readings of them. *International Journal of Science Education, 24*, 257-283.
A, C, D	47	Tytler, R., Peterson, S., & Prain, V. (2006). Picturing evaporation: Learning science literacy through a particle representation. *Teaching Science, 52*, 12-17.

Themes	ID	Citation
A, C, D	48	Tytler, R., Prain, V., & Peterson, S. (2007). Representational issues in students learning about evaporation. *Research in Science Education, 37*, 313-331.
A	49	Van Meter, P. (2001). Drawing construction as a strategy for learning from text. *Journal of Educational Psychology, 93*, 129-140. doi:10.1037//0022-0663.93.1.129
A, D	50	Van Meter, P., Aleksic, M., Schwartz, A., & Garner, J. (2006). Learner-generated drawing as a strategy for learning from content area text. *Contemporary Educational Psychology, 31*, 142-166.
A, C, F	51	Waldrip, B., Prain, V., & Carolan, J. (2010). Using multi-modal representations to improve learning in junior secondary science. *Research in Science Education, 40*, 65-80. doi:10.1007/s11165-009-9157-6
G, N, H	52	Wiebe, E., & Annetta, L. (2008). Influences on visual attentional distribution in multimedia instruction. *Journal of Educational Multimedia and Hypermedia, 17*, 259-277.

Appendix B

Examples of Carpet and Circle Diagrams

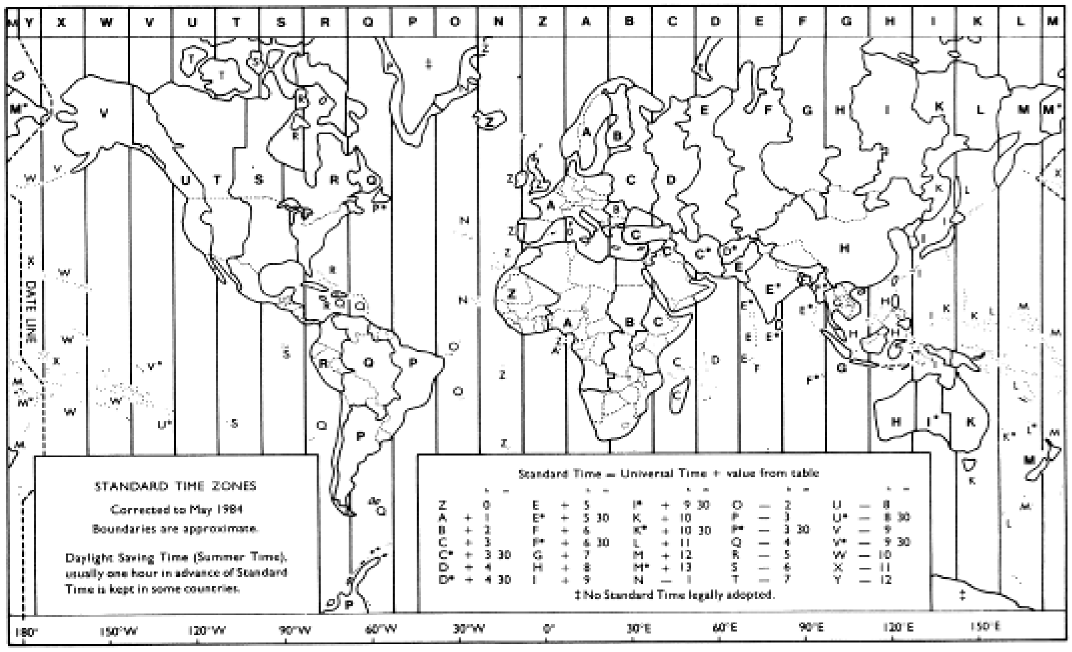


Figure B1. Carpet diagram showing time zones. Retrieved from http://www.netspeed.com.au/minnah/TimeZonesGS.GIF

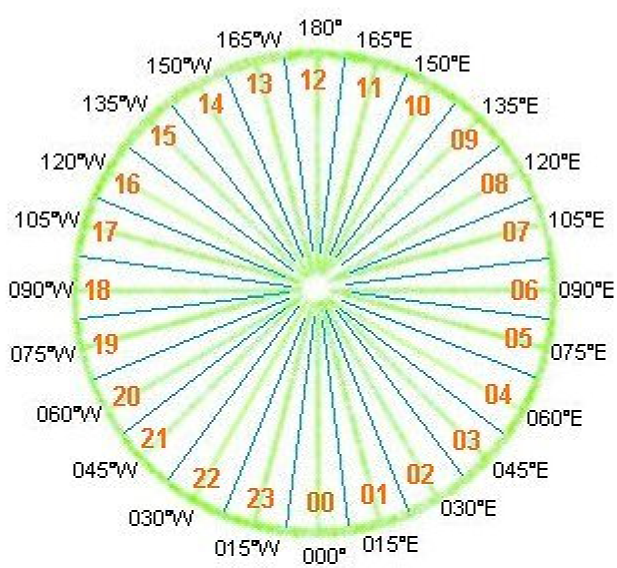


Figure B2. Circle diagram showing time zones. Retrieved from http://pilotsweb.com/navigate/art/timzone.jpg

Appendix C

Principal's Letter of Support

NORTH SAANICH
MIDDLE SCHOOL

RECEIVED
NOV 19 2008
HUMAN RESEARCH ETHICS

November 14, 2008

To Whom It May Concern:

I am pleased to continue to support the Saanich middle schools and Pacific CRYSTAL collaborative professional development and implementation project dealing with science literacy for all students. The project focuses on the enhanced use of science text and explicit instruction to improve students' reading, writing, representing, speaking and achievement in science. Specific science literacy strategies and tasks have been identified collaboratively by the North Saanich, Bayside, and Royal Oak middle school teachers and the researchers from the University of Victoria. I am aware of the project design and details, and I keep in contact with the Pacific CRYSTAL researchers.

I endorse the commitment of four full days of professional development during the 2008-2009 school year, to be sponsored by the Saanich School District (#63), CER-NET, and the Saanich Teachers Association, for Grades 6, 7, and 8 science teachers for the purpose of developing appropriate literacy-based tasks in the current science curriculum, implementing those tasks, evaluating the results, and developing unit plans that incorporate the promising strategies. These unit plans will be created for dissemination to other teachers, both in District 63 and in other school districts.

The documentation of students' science understandings, attitudes, and literacy skills will be undertaken in the spring by the classroom teachers along with Pacific CRYSTAL personnel (Dr. Robert Anthony, Dr. Larry Yore, and Christine Tippett). Pooled data from regular school-wide assessments will also be provided to the researchers at my discretion.

I will help facilitate the project by voluntarily obtaining informed consent from teachers and students and I will also inform parents about the continuation of the project. If additional information regarding my support of this project is required, please feel free to contact me at

Yours truly,

Principal

Appendix D

Consent Forms

University of Victoria

PO Box 3010 STN CSC
Victoria British Columbia V8W 3N4 Canada
Tel (250) 721-7808 Fax (250) 721-7598
Web www.uvic.ca/education/curriculum

Department of
Curriculum and Instruction

Teacher Consent Form

Pacific CRYSTAL: Explicit literacy instruction embedded in middle school science

Research Team:	Email address	Phone number
Dr. Robert Anthony	ranthony@uvic.ca	250-721-7886
Dr. Larry Yore	lyore@uvic.ca	250-721-7770
Christine Tippett	ctippett@uvic.ca	250-480-0923

Project Description: You are invited to participate in this collaborative project involving middle school science teachers and a research team from Pacific CRYSTAL, an NSERC initiative at the University of Victoria. The purpose of the project is to develop, field-test, refine, and disseminate authentic activities that support the development of literacy in the context of science instruction. Activities might include, but will not be limited to, genre writing (e.g., brochures, reports), reading comprehension strategies (e.g., THIEVES), vocabulary development, argumentation, and visual literacy strategies. We will investigate the effectiveness of these activities on students' literacy abilities (reading and writing) as well as examine teacher implementation of the activities. This project will benefit students, teachers, and the state of knowledge: an evidence-based description of these activities will enrich the repertoire of reliable instructional practices for teachers and will contribute to the theoretical literature on literacy and science learning.

Participation:

1. Participation is entirely voluntary and involves:
   - Attending four full day workshops and collaborating with the research team to identify and develop science literacy activities that will then be implemented.
   - Identifying and collecting samples of student work that exemplify the results of the activities and that demonstrate student achievement.
   - Participating in focus groups that may be audiotaped.
2. Participants may withdraw from the project at any time, without explanation. Any data already collected or contributed will be kept in the database.
3. The project will run for the 2009-20010 school year.
4. There are no known or anticipated risks to teachers or students arising from this project.

Anonymity, Confidentiality, and Disposal of Data

You will be taking part in focus groups and collaborative workshops, so other participants will be aware of your participation. However, pseudonyms will be used in all dissemination of the results of the project. Your confidentiality and the confidentiality of the data will be protected because all data will be stored in a locked filing cabinet or on a password protect computer. After five years, paper documents will be shredded, computer files will be overwritten, and audio tapes will be physically destroyed.

Dissemination of Results

It is anticipated that the results of this study will be disseminated through journal articles, presentations at scholarly meetings, teacher workshops, and a dissertation.

Contacts

If you have any questions, you may contact any member of the research team. In addition, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Human Research Ethics Office at the University of Victoria (250-472-4545 or ethics@uvic.ca).

Your signature below indicates that you understand the above conditions of participation in this study and that you have had the opportunity to have your questions answered by the researchers.

______________________ ______________________ ______________

Name of Participant *Signature* *Date*

A copy of this consent will be left with you, and a copy will be taken by the researcher.

PO Box 3010 STN CSC
Victoria British Columbia V8W 3N4 Canada
Tel (250) 721-7808 Fax (250) 721-7598
www.educ.uvic.ca/edci

Department of Curriculum
and Instruction

University
of Victoria

Student Consent Form

Pacific CRYSTAL: Explicit literacy instruction embedded in middle school science

Research Team:	Email address	Phone number
Dr. Robert Anthony	ranthony@uvic.ca	250-721-7886
Dr. Larry Yore	lyore@uvic.ca	250-721-7770
Christine Tippett	ctippett@uvic.ca	250-480-0923

Project Description: You are invited to participate in this collaborative project involving middle school science teachers and a research team from Pacific CRYSTAL, an NSERC initiative at the University of Victoria. The purpose of the project is to develop, field-test, refine, and disseminate authentic activities that support the development of literacy in the context of science instruction. Activities might include, but will not be limited to, genre writing (e.g., brochures, reports), reading comprehension strategies (e.g., THIEVES), vocabulary development, argumentation, and visual literacy strategies. We will investigate the effectiveness of these activities on students' literacy abilities (reading and writing) as well as examine teacher implementation of the activities. This project will benefit students, teachers, and the state of knowledge: an evidence-based description of these activities will enrich the repertoire of reliable instructional practices for teachers and will contribute to the theoretical literature on literacy and science learning.

Participation:

1. Participation is entirely voluntary and involves:
   - Sharing your opinion about classroom science activities through informal questioning.
   - Providing samples of your work that show the results of the activities. You will sign a separate form for each piece of your work.
2. You may choose not to participate at any time, without explanation. Your grades will not be affected by whether or not you choose to share your opinions or work samples. If you do decide to withdraw from the study, any data already collected or contributed will be kept in the database.
3. The project will run for the 2009-2010 school year.
4. There are no known or anticipated risks to teachers or students arising from this project.

Anonymity, Confidentiality, and Disposal of Data

You will be answering questions and sharing work samples during class time, so other students might knpw that you are participating in the project. However, pseudonyms will be used in all dissemination of the results of the project. Your confidentiality and the confidentiality of the data will be protected because all data will be stored in a locked filing cabinet or on a password protect computer. After five years, paper documents will be shredded, computer files will be overwritten, and audio tapes will be physically destroyed.

Dissemination of Results

It is anticipated that the results of this study will be shared with others through journal articles, presentations at scholarly meetings, teacher workshops, and a dissertation.

Contacts

If you have any questions, you or your parents may contact any member of the research team. In addition, your parents may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Human Research Ethics Office at the University of Victoria (250-472-4545 or ethics@uvic.ca).

Your signature below indicates that you understand the above conditions of participation in this study and that you have had the opportunity to have your questions answered by the researchers.

______________________	______________________	______________
Name of Participant	*Signature*	*Date*
______________________	______________________	
Name of Parent	*Signature*	

A copy of this consent will be left with you, and a copy will be taken by the researcher.

Appendix E

School Wide Write Teacher Materials

(Developed by the School-Based Literacy Team)

School Wide Write

Objective: To determine individual students' ability level with regards to impromptu writing.

Teacher's Viewing and Writing Process Guide:

1. Book a copy of Ice Age for your preferred test time (Wed, Thurs or Fri), and sign out DVD player through the library sign-out sheet. Below is a script to follow to introduce the process with your class. You may wish to choose one graphic organizer for your students or provide them with a choice. (See examples enclosed in the package)
2. Set aside a double block for the entire School Wide Write. (This may mean making arrangements with another teacher to start or continue the process if you only have a class for one block)
3. Follow the implementation protocol. (see below)

Implementation Protocol

- "*Today we are going to administer our School Wide Write Assessment. This is an opportunity for teachers to determine how well you are able to complete a recount write.*"
- (To be used with the overhead titled "Recount Writing")

  "*Recount writing is a retelling of specific events. Recount writing has several specific features:*

  -An introduction that includes setting and information about who, what, where, when and why.

  -A chronological explanation of the events, (could include such linking words as Then, When, After)

  -Written in past tense.

  -A conclusion that includes a reflection and evaluation of the incident."
- *"I will pass out a copy of the rubric for you to look at to gain a better understanding of how you will be marked."* Teachers may spend a few minutes discussing the rubric.
- "*You will begin by watching a five minute DVD clip without narrative. In the five-minute DVD, we meet Scrat, a prehistoric squirrel. He has been gathering and storing acorns for the coming winter. The first time you watch the DVD, you will be asked to watch and listen only, and not take any notes. Then, you will watch the DVD a second time at which time you will be making notes to record the events that occurred. You will be provided with a graphic organizer to use for note making. From the notes you have created, you will recount the events of the DVD clip you have watched."*
- Watch the DVD for the first time. To access the segment, turn on DVD player and press play. It will be the first five minutes of the DVD; there is no narration.

  Say: *"Remember, you are to watch and listen only during the first viewing."*
- Before the second viewing, distribute the graphic organizer.

- *"While you are watching the DVD a second time, write down only the key words to help you remember the order of the events that you are watching. After the second viewing of the DVD, you will have 5 minutes to complete your note making on the graphic organizer*."
- After 5 minutes, set a 30 minute time limit for students to write the recount of the events. *"You will now have 30 minutes to write your recount of the events from the DVD".*
- If you have time, staple the rubric to the students' note making graphic organizer and the recount write.

SWW Overhead

Recount Writing

Recount writing is retelling of specific events.

Recount writing has several specific features:

-An introduction that includes setting and information about who, what, where, when, and why.

-Chronological explanation of the events, (could include such linking works as Then, When, After)

-Written in past tense.

-Conclusion that includes a reflection and evaluation of the incident.

Quick Scale: Grade 6 Personal Writing

This Quick Scale is a summary of the Rating Scale that follows. Both describe student achievement in March-April of the school year. Personal writing is usually expected to be checked for errors but not revised or edited.

Aspect	Not Yet Within Expectations	Meets Expectations (Minimal Level)	Fully Meets Expectations	Exceeds Expectations
SNAPSHOT	*The writing offers some ideas related to the topic but is often hard to follow. The writer may need a great deal of support.*	*The writing is somewhat general but completes the basic task; includes some errors.*	*The writing is straight-forward, direct and easy to follow, with few errors. Develops the topic and offers some personal reactions.*	*The writing is focused and easy to read. The writer develops ideas with some analysis and complexity.*
MEANING • ideas and information • use of detail	• some ideas related to the topic; tends to rely on retelling or listing • parts are inaccurate, illogical, repetitive, irrelevant, or copied • insufficient details, explanations, examples; often extremely short	• some opinions and reactions • information and ideas are relatively simple • some explanation, details, and examples (may be very brief or partly irrelevant)	• relevant personal reactions and ideas with some individuality • ideas and information are direct and straight-forward • some relevant explanations, details, and examples	• relevant personal reactions and ideas with some analysis; sense of individuality • ideas and information show some complexity • logical explanations, details, and examples
STYLE • clarity, variety, and impact of language	• simple, repetitive language; may make errors in word choice • sentences are often short and repetitive	• language tends to be simple and often vague • sentence length may be varied; relies on a few basic patterns	• language is clear; some variety and description • variety of sentence lengths; may vary sentence beginnings	• language is clear, varied; some precise, expressive language • flows smoothly, with a variety of sentence lengths and patterns
FORM • opening • organization and sequence • conclusion • connecting words	• begins without establishing the topic, purpose, or context • may attempt to develop the topic, but often wanders, loses focus • no real "ending" • overuses simple connecting words	• introduces the topic; purpose and context may be omitted or unclear • generally sticks to the topic and is easy to follow, but may wander in places • ending is weak or abrupt • may overuse a few connecting words	• introduces the topic and purpose; may provide some context • sticks to the topic; easy to follow, with related ideas grouped together • ending is logical but abrupt • uses a variety of connecting words	• opens with a clear intention or purpose; provides context • develops the topic with a logical sequence of ideas • effective ending • uses increasing variety of transitional words and phrases; may take risks
CONVENTIONS • spelling • punctuation • complete sentences • grammar	• frequent errors interfere with meaning	• some noticeable errors; these may cause the reader to hesitate or reread parts to confirm meaning	• few errors; these do not interfere with meaning	• sense of control; few errors; these are usually the result of taking risks to use complex language and structures

GRADE 6 PERSONAL WRITING 213

SWW Rubric from the *BC Performance Standards* (Ministry of Education, Province of British Columbia, 2009).

Appendix F

District Assessment of Reading Task Materials

DART Protocol

District Assessment of Reading Team (DART)
Fall Reading Assessment FOR Learning
PROTOCOL for Grade 6 *Storm Chasers*

In this Fall Grade 6 DART Assessment students read all of ***Storm Chasers.*** Some students may recognize the text because they read the first 5 pages of ***Storm Chasers*** in Grade 5 as their DART Spring Assessment.

Setting the stage for the DART Assessment takes approximately 15 minutes. Students will need 45 minutes to complete the reading and Question and Answer Sheet. This assessment will take 2 teachers one hour to administer. If a second teacher is not available additional time will be necessary for a teacher to complete the Oral Reading and Conference components.

Teacher materials required:
1. Copy for each teacher of the Oral Reading Sheet.
2. (Optional) Overhead of the front page of the article.
3. Oral Reading/Conference Sheet for each student.

Student materials required
1. class set of Question and Answer Sheets.
2. class set of ***Storm Chasers*** booklets.

Assessments should allow students to exhibit their strengths. With this in mind, review the following purposes and processes with the students. The following script is provided for your use.

There may be some students in your class on modified programs who will not be able to read this text. If so, in accordance with their I.E.P., the text may be read to them and they could respond to the best of their ability.

Rationale	Steps	Points to Consider
It is important that students understand the **purpose of the assessment** and how the information is going to be used.	"The **purpose** of this reading assessment is to gain information about how well you are independently reading and understanding at this time of the year, using a particular sample. I will use what I learn from this assessment to guide my planning. It is not an assessment for marks." "You will be asked to read silently and to answer a few questions." "This is an independent reading Sample." "At anytime, you can look at the text to answer the questions."	Make sure the students know what you want them to do after they have finished, and that they have the necessary materials in their desks. Silent reading is easy to organize and appropriate.

Brownlie: DART Protocol

Rationale	Steps	Points to Consider
Proficient readers **access background knowledge (schema)** before they read to increase their understanding.	"It is important to think about the title and the picture on the cover before you read. Look at the cover of this text entitled ***Storm Chasers.*** How many of you remember reading this in the Spring? We are going to read the whole booklet today. The questions are based on information in the last half of the booklet." What do you think the rest of this text is going to be about? What do you already know about storm chasers?" Ask class to share predictions and facts they know about the topic so everyone hears the same information. After students have shared with the whole class, encourage individual student accountability. "Close your eyes, think about what you have heard and already know about **storms and storm chasers**. Make a fist and raise a finger with each fact you recall."	You could show a colour overhead of the booklet cover.
Proficient readers read with a **purpose**.	Distribute Student Assessment Packages. "Let's read the questions over BEFORE you begin reading, to help establish your **purpose** for reading." "I will read the questions aloud while you follow."	The questions are not discussed. If a student requires support with a question during the assessment and if support is given, record this information for use in planning for instruction.
Proficient readers **interact with the text** during reading to deepen their understanding.	Encourage your students to use strategies to **hold their thinking** as they read. "I can give you stickies, acetate or scrap paper to hold your thinking because you cannot write on your text."	Use these if you feel they will be helpful to your students.

- McMahan and Bjornson. March. 2005.

2

Rationale	Steps	Points to Consider
The oral reading provides a great deal of information about the **strategies that students** use when decoding and comprehending text.	"You now know what your part is in this assessment. I also have a part to do. My part is to listen to you read, make notes and ask you a few questions." "**Reading orally** provides a window into what goes on in your mind when you read. I glimpse your reading patterns, how you make sense of unknown words, your phrasing, the flow of your language. This information helps me support you in your development as a reader." "You will be asked to read something in the passage that you have already practiced. All students will read the same passage. I will mark down what I notice about your reading. What I am marking is my observations, not necessarily errors. I will show you my recording, once we have finished." Students will read from their copy of the article. Record your observations on the Oral Reading Sheet. Circle the appropriate descriptor(s) at the bottom of the page eg. careful and confident.	It is important that all students read aloud. One to one time is valuable. Struggling readers are not centered out. If students are unfamiliar with the coding system you may wish to explain it to the class before you begin the assessment. Most students are comfortable with reading aloud in the classroom, while others may wish to go to another setting. It is helpful to copy the Conference Sheet and the Oral Reading Sheet back to back.
The conference allows further insight into **strategy use** and allows students who are challenged with putting their thoughts on paper to **demonstrate their understanding orally**.	"After I listen to you read I will **conference** with you. I will ask you about the strategies you used, what you learned from your reading and what connections you made as you read."	When you ask the questions about strategy use do not show students the potential answers. Either tick, number or record their answers. If you notice a huge discrepancy between a student's oral answers and their written responses ask the comprehension questions.

Reading Behaviour	Code
Omission	home
Insertion	old My^house
Substitution	house ~~home~~
Repetition	R
Sounding Out	SO
Self-Correction	SC
Told student the word	T
Pause	he | told

- Brownlie: DART Protocol
- McMahan and Bjornson. March. 2005.

3

Rationale	Steps	Points to Consider
	Distribute booklets. Remind students to be thoughtful in answering the comprehension questions and remind them that they can look back at the text as they need to. Remind the students to read the whole booklet, **Storm Chasers**, even though most of the information to answer the questions will be in the last half.	Give the students about 5 minutes to settle before you start the Oral Reading and Interviews.
Assessments should allow students to **exhibit their strengths**.	Give students the time they need to finish the assessment.	It usually takes most students between 45 and 60 minutes.

- Brownlie: DART Protocol
- McMahan and Bjornson. March. 2005.

DISTRICT ASSESSMENT OF READING TEAM (DART)
ORAL READING

GRADE
6
FALL 2004

Storm Chasers (Ed Stanley)

Name: ______________________ Date: ________________

Spotting Storms

Storm spotters are often volunteers. They spend hours watching the skies for signs of a storm. They know what to look for and how to relay what they see. Most of them work as part of a network. When they sight signs of a severe storm, they report it to their local weather centre. This information is then sent to towns and cities to warn them of the coming storm.

Some storm spotters move from place to place in their cars or trucks but most spot storms from fixed places. Spotters play an important role. Even with today's advanced radar systems, their reports help save lives and property.

Safety First

Storm chasing is dangerous. The best storm chasers respect the awesome forces of nature. They have studied weather patterns and have learned much about severe storms. They get just close enough to watch a storm but stay far enough away to be safe. Only the experts should chase storms. When a storm warning is in effect, all others should follow safety guidelines.

Halting Careful Confident / Fluent Expressive

Storm Chasers - fall

	Easy or Independent				/	Instructional					/ Difficult
%	99	98	97	96	95	94	93	92	91	90	89-
errors	1-2	3-4	5-6	7	8-9	10-11	12-13	14	15-16	17-18	19+

FALL ASSESSMENT (DART)
QUESTION AND ANSWER SHEET

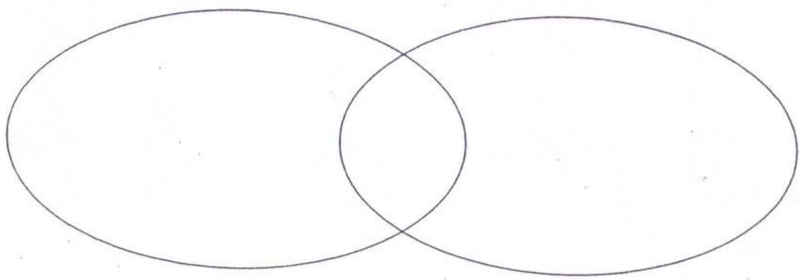
GRADE
6
FALL

School: ____________________

Name: ____________________ ☐ Female ☐ Male Date: ____________________

Storm Chasers (Ed Stanley)

1. Use the Venn diagram below to show the similarities and differences between tornadoes and hurricanes.



2. Explain, in your own words, the diagram on page 6, 'How a Tornado Forms'. Use information from the diagram, from the reading, and from your background knowledge in your explanation.

____

____

____

____

DART Rubric Part 1

I

District Assessment of Reading Team (DART)

DART Oral Reading Fluency Guidelines

1 **Halting**
- Little expression, monotone
- Short phrases
- Slow with long pauses and repetitions

2 **Careful**
- Some expression that conveys meaning
- Longer word phrases some of the time
- Moderate rate with some pauses and repetitions
- Little flow

3 **Confident**
- Expression generally reflects mood and pace
- Longer, meaningful phrases some of the time
- Rate with a few pauses or repetitions
- Sounds like talk

4 **Fluent**
- Expression reflects mood and pace
- Longer, meaningful phrases most of the time
- Good rate – flow – may be an occasional pause

5 **Expressive**
- Very expressive in the mood and pace – like a performance
- Consistently longer, meaningful phrases
- Rate reflects the 'passion' of the author's voice

(Adapted from fluency standards in Developmental Reading Assessment (DRA) kit, 4-8)

Teacher Observation Guide	Linda Greenlaw			*Level 60, Page 6*
Engagement	Intervention	Instructional	Independent	Advanced
Wide Reading	1 General reading materials (*e.g.*, chapter books, comics) or 1 text	2 Titles generally below-grade-level; limited reading experiences	3 Some titles within 2–3 genres or multiple books within a genre; generally on-grade-level texts	4 Wide variety of titles across 3 or more genres; many on- and above-grade-level texts

DART Rubric Part 2

.ag Scale: Grade 6 Reading for Information

*Student achievement in reading for information by March-April of Grade 6 can generally be described as shown in this scale.**

Name: ______________________

☐ Fall
☐ Spring Year______________

Aspect	Not Yet Within Expectations	Meets Expectations (Minimal Level)	MEETS	Fully Meets Expectations	Exceeds Expectations
Snapshot Note: the snapshot can be used alone as a holistic scale for marking some assignments	*With support, the student is able to read brief, straightforward information and procedural texts with familiar language and simple graphics. Work may be inaccurate for incomplete. Often needs one-to-one support to complete tasks*	*The student is able to read straightforward information and procedures, including illustrations and other graphics (as described in the chart on page 188) but may have difficulty with specialized language and complex ideas. Work is often inconsistent: parts are accurate and complete; other parts are vague, incomplete, and lack detail.*		*The student is able to read straightforward information and procedures, including illustrations and other graphics, that include some specialized language and complex ideas (as described in the chart on page 188). Work is generally accurate and complete, with specific references to selection*	*The student is able to read elaborated information and procedures, including illustrations and other graphics, that include specialized language and complex ideas. Completes assigned tasks independently, thoroughly, and efficiently, often exceeding requirements of the task.*
LEVELS					
STRATEGIES					
• predicting	• has difficulty predicting content; may offer illogical guesses	• makes simple logical predictions about content based on text features and prior knowledge		• makes logical predictions about content based on prior knowledge and text features; may be able to predict structure	• anticipated content and structure by drawing on prior knowledge and text features
• word skills	• tends to sound out new words; may give up easily	• uses sounding out, context clues, and dictionaries; may not notice word parts in technical specialized language		• uses context clues, word structure, graphic clues, glossaries, and dictionaries to figure out unfamiliar words; may have some difficulty with technical or specialized language	• independently uses context clues, word structure, graphic clues, glossaries, and dictionaries to figure out technical and specialized vocabulary
• checks understanding	• often focuses strongly on decoding and does not check for understanding; needs help to select and use appropriate comprehension strategies	• checks understanding and adjusts comprehension strategies if prompted		• checks for understanding; adjusts comprehension strategies to deal with specific problems or features of the material	• evaluates own understanding; makes deliberate and effective choices about how to approach challenging material
• locating detail	• guesses or tries to recall details rather than rereading text to find details needed for a question or activity	• can locate some information needed for a question or activity; often incomplete		• rereads and skims to find relevant, specific details to complete questions	• quickly and efficiently finds specific details to complete questions or activities
• text features	• needs assistance to use text features (e.g., headings, diagrams)	• may need prompting to use text features		• uses text features effectively to preview and locate information	• uses text features effectively to preview, locate and organize information
COMPREHENSION					
• accuracy and completeness	• responses to comprehension questions or tasks are often inaccurate or based solely on prior knowledge; often vague or incomplete	• most responses to comprehension questions or tasks provide accurate information, but they may be vague, incomplete		• responses to comprehension questions or tasks are clear, complete, and based on accurate information from the text	• responses to comprehension questions are precise and thorough; may be insightful
• main ideas	• has difficulty identifying main ideas, distinguishing between main ideas and supporting details	• identifies most main ideas; often has trouble restating them in own words		• accurately identifies main ideas; may need prompting to restate in own words	• accurately restates main ideas in own words; may be able to explain some connections between them
• details	• may identify some relevant supporting details; omits a great deal	• identifies relevant supporting details; may miss some		• identifies relevant supporting details to respond to questions or tasks	• identifies specific, relevant details to respond to questions or tasks; detailed and thorough
• note-making	• has difficulty making notes, even when provided with a template or organizer; often omits information or records it in incorrect categories	• makes simple notes if given a template or organizer; has difficulty choosing own categories		• makes accurate notes, using simple, logical categories or headings	• makes accurate, organized notes by creating categories or heading that reflect all or most of the main ideas or topics
• inferences	• misinterprets literal information	• interprets all or most literal information accurately; makes some inferences, but these may be illogical		• accurately interprets literal information, including information from graphic features: some inferences may be unsupported by evidence from the text	• makes simple, logical inferences and interpretations, and provides specific evidence from the text and graphic features if asked
ANALYSIS					
• connections to other information	• may have difficulty seeing how new information connects to prior knowledge; prior knowledge may be limited	• makes some simple, obvious connections between new information and prior knowledge		• makes logical connections between new information and ideas and prior knowledge and beliefs about the topic	• compares new information and ideas and prior knowledge and beliefs about the topic; may show insight through analysis or explanation
• evaluation/ reflections	• reactions or judgements are often vague or unsupported	• offers some simple reactions or judgements; reasons are often vague		• offers simple reactions or judgements; reasons may be vague	• offers reactions or judgements with reasons; may evaluate information in terms of prior knowledge

Student performance that falls within the wide range of expectations for Grade 6 by March-April generally matches the "Functional" and "Purposeful" descriptions in Evaluating Reading Across Curriculum.

Grade 6 Fall DART Booklet

Storm Chasers

Written by Ed Stanley

Pearson Education Canada

DARK SKIES AHEAD

Giant clouds move across the sky—not big, white clouds, but black thunderheads. The air grows thick. Thunder rumbles and lightning strikes in the distance. A musty smell fills the still air. The sky turns green as sirens begin to blare a tornado warning. A scientist and his team scramble into their cars. Unlike most people, they want to get as close as they safely can to watch the oncoming storm. They are storm chasers.

WHAT ARE STORM CHASERS?

Storm chasers are people who want to know more about severe storms. They spend days tracking storm systems. They try to predict where and when storms might form. They may travel alone or in teams. Some storm chasers are photographers, others are researchers, and a few are pilots. Each group has its own reason for chasing storms.

Taking Pictures of Storms

Warren Faidley is a photographer of severe weather. He has taken pictures of some of the world's worst storms. He began taking pictures of the skies while working for a newspaper. He started selling photos of lightning, then hurricanes and tornadoes. Faidley learned about all types of storms. This way, he could safely be in the right place at the right time for the best storm pictures.

Faidley spends lots of time on the road chasing storms. He drives a special SUV he calls Arch Angel. It is packed with special gear and flashing lights. He also has video cameras and cell phones.

Lightning can strike several kilometres in front of a storm.

Faidley likes to photograph lightning at sunset. The clouds are filled with colour at that time. He says that the sky is nature's canvas. He likes to capture nature's artwork with his camera.

Taking pictures of lightning is dangerous. Lightning kills more than 100 people each year in North America. It can strike several kilometres in front of a storm. Lightning seeks out an easy route to the ground. It often strikes things made of metal. Since cameras are made of metal, Faidley needs to be very careful. Like many storm chasers, he doesn't always find a storm when he goes out. He keeps searching because the next storm he finds may be the best one ever.

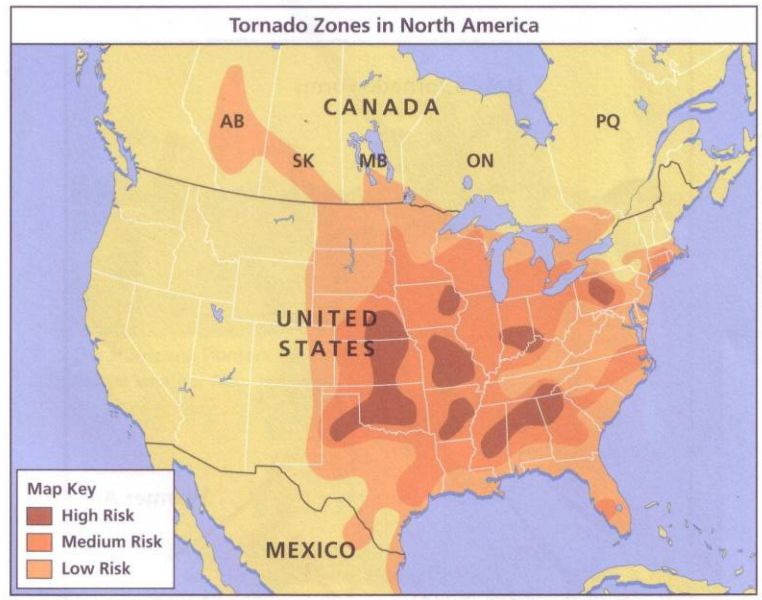
Tracking Down Tornadoes

Some storm chasers are researchers. They study storms to learn more about them. Their research helps improve weather forecasting and severe-storm warnings. They hope to find ways to save lives and property.

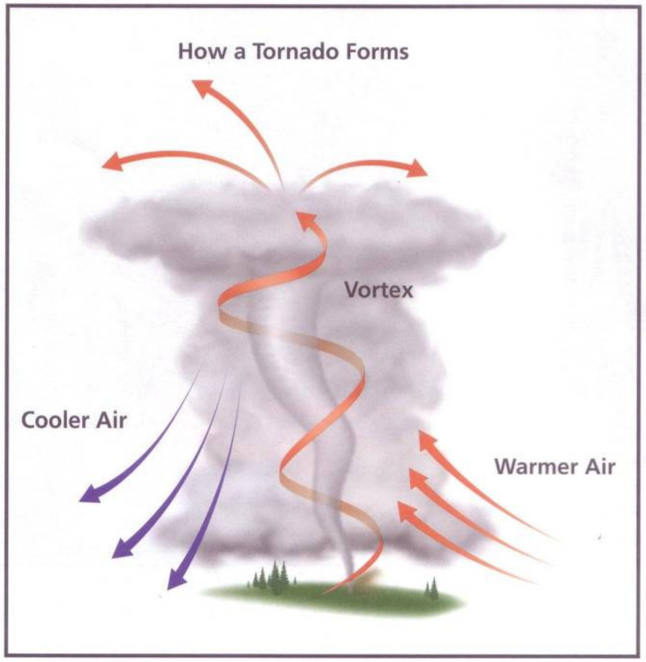
Researchers follow storms to learn more about them.

Some researchers do tests to learn more about tornadoes. They have learned to predict where and when tornadoes might form. They have studied weather maps and wind patterns. And they also have learned to read the sky.

Tornadoes are hard to find. Only about 1 in 10 chases results in spotting one. One chase can cover a great distance. Researchers use weather tools and maps to find storms. Sensors on top of their cars record lightning strikes far away. Storm chasers use computers to check reports from weather centres across North America. They use maps to find the best route. They must be able to change routes as quickly as the storm they are chasing. Today, there are better warning systems due to the work of these storm chasers.



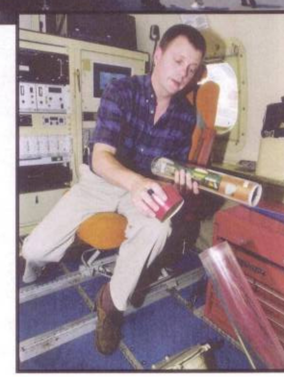
Each year more than 1000 tornadoes are sighted in North America. They kill more than 80 people and injure more than 1500. They also cause much damage. Most of them form in the midwest region. Tornadoes are caused by the clash of a cool, dry air mass with one that is hot and moist. When the two meet, the cooler air swoops down as the warmer air rises. This motion can create a spiralling wind, or vortex. It is like water swirling down the drain in a sink. As the vortex spins, it can form a funnel with winds up to 480 kilometres per hour (km/h).



Hunting Hurricanes

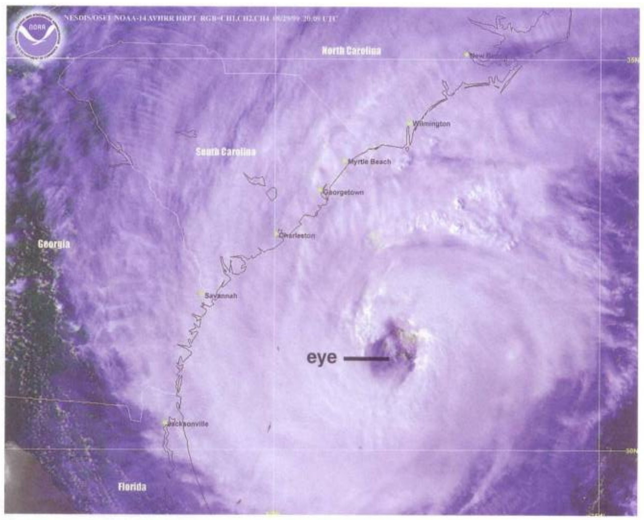
Hurricane Hunters have a special mission. They watch for and report on severe weather from the air. They fly during the hurricane season, from June 1 to November 30. They also track winter storms from both coasts. These storms can be just as severe as some hurricanes.

The Hurricane Hunters report on severe weather from the air.



A dropsonde

These pilots fly as low as possible. They observe the weather at the bottom of the storm. They also fly right into the dark storm clouds around the eye or centre of the hurricane. That's where they drop a tool called a dropsonde. It goes through the eye. Then it sends data back to the airplane. This data helps hurricane forecasters track the movement and power of the storm.



This satellite photograph shows the eye of a hurricane.

Hurricanes are severe, tropical storms. They can be more than 320 kilometres wide. Winds in a hurricane can reach speeds of more than 240 km/h. These strong winds can create giant waves almost 8 metres high. Forecasters give hurricanes names to help people know which storm is coming their way.

They also assign a hurricane a number from 1 to 5 to tell people about how much damage it might cause. Thanks to the work of the Hurricane Hunters, people are better prepared for a coming storm. As a result, less property and fewer lives are lost.

SPOTTING STORMS

Storm spotters are often volunteers. They spend hours watching the skies for signs of a storm. They know what to look for and how to relay what they see. Most of them work as part of a network. When they sight signs of a severe storm, they report it to their local weather centre. This information is then sent to towns and cities to warn them of the coming storm.

Storm chaser Dan Wexler spends hours watching the skies over Canada for signs of a storm.

Some storm spotters move from place to place in their cars or trucks but most spot storms from fixed places. Spotters play an important role. Even with today's advanced radar systems, their reports help save lives and property.

SAFETY FIRST

Storm chasing is dangerous. The best storm chasers respect the awesome forces of nature. They have studied weather patterns and have learned much about severe storms. They get just close enough to watch a storm but stay far enough away to be safe. Only the experts should chase storms. When a storm warning is in effect, all others should follow safety guidelines.

Level 50

The following people have contributed to the development of this product:

Editorial: Wendy Gdanski, Lynn Trepicchio
Canadian Edition: Angelie Kim, Sharon Stewart, Rena Sutton, Rebecca Vogan
Art and Design: Sharon Bozek, M. Jane Heelan, Judy Mates, Heather Wendt Kemp
Canadian Edition: Jennifer Federico, Janet Zanette
Production: Helen Gocher, Cynthia Lynch
Canadian Edition: Zane Kaneps

Photographs: Cover: © Howard Bluestein/Photo Researchers, Inc. 3: Warren Faidley/WeatherStock. 4: NOAA Photo Library, NOAA Central Library; OAR/ERL/National Severe Storms Library (NSSL). 7: *t.* AP Photo/Morning News, John W. Liston, *b.* AP Photo/Chris O'Meara. 8: AFP Corbis. 9: DanWexler/Canadian Stormchaser.

Illustrations/Maps: 5: Deborah Crowie. 6: Argosy.

ISBN 0-13-122594-4

Printed in Canada

2 3 4 5 6 7 8 9 10 MP 07 06

www.pearsoned.ca

PEARSON Education Canada

ISBN 0-13-122594-4
9 780131 225947

Appendix G

The Science Curriculum Implementation Questionnaire

(SCIQ, Lewthwaite & Fisher, 2005)

There are 49 items in this questionnaire. They are statements to be considered in the context of the school in which you work. Think about how well the statements describe the school environment in which you work.

Indicate your answer on the score sheet by circling:

SD if you *strongly disagree* with the statement;
N if you *neither agree nor disagree* with the statement or are not sure;
SA if you *strongly agree* with the statement;
D if you *disagree* with the statement;
A if you *agree* with the statement;

If you change your mind about a response, cross out the old answer and circle the new choice.

1. Teachers at this school have a good understanding of the science knowledge, skills and attitudes they are to promote in their teaching. SD D N A SA
2. Teachers have a positive attitude to the teaching of science. SD D N A SA
3. The school is well resourced for the teaching of science. SD D N A SA
4. Teachers at this school are adequately prepared to teach science. SD D N A SA
5. The school administration recognizes the importance of science as a subject in the overall school curriculum. SD D N A SA
6. There is not enough time in the school program to fit science in properly. SD D N A SA
7. Teachers at this school have the opportunity to receive ongoing science curriculum professional support. SD D N A SA
8. Teachers at this school have a sound knowledge of strategies known to be effective for the teaching of science. SD D N A SA
9. Teachers at this school are reluctant to teach science. SD D N A SA
10. The school-based system of managing of science resources is well maintained. SD D N A SA
11. Teachers at this school are confident science teachers. SD D N A SA
12. The school's ethos positively influences the teaching of science. SD D N A SA
13. There is enough time in the school week to do an adequate job of teaching the requirements of the science curriculum. SD D N A SA
14. Collegial support is a positive factor in fostering the implementation of science programs in this school. SD D N A SA
15. Teachers have a sound understanding of alternative ways of teaching scientific ideas to foster student learning. SD D N A SA
16. Teachers have a strong motivation to ensure science is taught at this school. SD D N A SA
17. Teachers at this school have ready access to science materials and resources. SD D N A SA
18. Teachers at this school are competent teachers of science. SD D N A SA
19. The school places a strong emphasis on science as a curriculum area. SD D N A SA
20. The school curriculum is crowded. Science suffers because of this. SD D N A SA
21. The collegial support evident in this school is important in fostering capabilities in teachers who find science difficult to teach. SD D N A SA

22. Teachers at this school are secure in their knowledge of science concepts pertinent to the science curriculum. SD D N A SA
23. Teachers at this school have a positive attitude to science as a subject in the overall school program. SD D N A SA
24. The facilities at this school promote the teaching of science. SD D N A SA
25. Teachers possess the personal confidence, and skills necessary to teach science competently. SD D N A SA
26. Science has a high profile as a curriculum area at this school. SD D N A SA
27. There is not enough time in the school program to teach science. SD D N A SA
28. Teachers have the opportunity to undertake professional development in science. SD D N A SA
29. Teachers at this school possess the necessary science subject knowledge to be a good science educator. SD D N A SA
30. Science is a subject at this school that teachers want to teach. SD D N A SA
31. The science resources at the school are well organized. SD D N A SA
32. Teachers at this school have positive perceptions of their competence as science educators. SD D N A SA
33. Science has a high status as a curriculum area at this school. SD D N A SA
34. Teachers believe that there is adequate time in the overall school program to teach science. SD D N A SA
35. Teachers at this school are supported in their efforts to teach science. SD D N A SA
36. Teachers at this school have a good understanding of students' science background knowledge and thinking. SD D N A SA SD D N A SA
37. Teachers at this school have a negative attitude to science as an essential learning area. SD D N A SA SD D N A SA
38. The equipment that is necessary to teach science is readily available. SD D N A SA
39. Teachers at this school are adequately prepared to teach to the requirements of the science curriculum. SD D N A SA
40. Science as a curriculum area is valued at this school. SD D N A SA
41. Teachers have the time to effectively deliver the requirements of the national science curriculum. SD D N A SA
42. The senior administration actively supports science as a curriculum area. SD D N A SA
43. Teachers have clear understanding of the goals and objectives of the science curriculum. SD D N A SA
44. Teachers at this school are motivated to make science work as a curriculum area. SD D N A SA
45. The school has adequate science equipment necessary for the teaching of science. SD D N A SA
46. Teachers at this school have a negative self-image of themselves as regards their ability to teach science. SD D N A SA
47. Science is regarded as an important subject in the school's overall curriculum. SD D N A SA
48. Time is a major factor inhibiting science program delivery at this school. SD D N A SA
49. The curriculum leadership in science fosters capabilities in those who require support in teaching science. SD D N A SA

Appendix H

Representational Competence Assessment Materials

(Preassessment Measure)

What are the parts of the Sun?

The Sun is a huge sphere made up mostly of two very light gases, hydrogen and helium. About 71% of the Sun's mass is made up of hydrogen. Another 27% is made up of helium. Other materials, such as oxygen and carbon, make up the remaining 2% of the Sun's mass.

Most of the energy that the Sun produces is formed in its core. At its core, the Sun has a temperature of 10 million to 20 million degrees Celsius. The pressure is more than 1 billion times greater than the air pressure at sea level on Earth.

The radiation layer, which is next to the core, moves the energy produced in the core in every direction. It can take millions of years for energy to move out of this layer.

In the convection layer, gases with different energies move in circles in a way similar to air with different densities. Energy moves out of this layer in about a week.

The photosphere is the visible surface of the Sun. It is not a solid surface, but rather a layer of gases. The photosphere is cooler than the core. Its temperature is about 5,730°C (10,346°F).

The next layer of the Sun is the chromosphere, or the inner layer of the Sun's atmosphere. When it can be seen, it looks like a red circle around the Sun.

The corona is the outermost layer of the Sun's atmosphere. The corona takes on different shapes around the Sun depending on changes in the temperature of the photosphere.

Visually represent the information contained in the paragraphs you have just read.

(Postassessment Measure)

The Earth's Atmosphere

The Earth's atmosphere is a thin layer of gases that surrounds the Earth. About 78% of the atmosphere is nitrogen. Another 21% is oxygen. Other gases, such as argon and helium, make up the remaining 1%.

The densest layer of the atmosphere is the troposphere, a thin layer at the Earth's surface that is about 17 kilometres thick. Almost all weather occurs in this layer, which contains most of the moisture and air in the atmosphere.

The stratosphere is the layer above the troposphere. The earth's ozone layer is located in the stratosphere. Ozone is crucial to our survival as it absorbs a lot of the Sun's ultraviolet rays.

The mesosphere is the next layer of the Earth's atmosphere. It is the layer where most meteors burn up. The upper edge of the mesosphere is the coldest place on Earth and has an average temperature around –100 °C.

The ionosphere extends from 80 to 640 kilometres above the Earth. The Northern Lights occur in this layer. The temperature of the ionosphere can rise to 1,500 °C. The International Space Station orbits in this layer.

The outermost layer of Earth's atmosphere is the exosphere. It extends from 640 kilometres above the Earth and outwards. Here the particles are so far apart that they can travel hundreds of kilometres without colliding with one another. The exosphere is mainly made up of hydrogen and helium.

Visually represent the information contained in the paragraphs you have just read.

Appendix I

Checklist for Visual Representations

	Format:
	▪ picture or drawing
	▪ graph/chart: bar / pie / other (specify)
	▪ diagram
	▪ graph/chart **and** diagram
	▪ separate
	▪ combined
	Information Conveyed:
	▪ none evident
	▪ temperature
	▪ chemical composition
	▪ layers
	▪ chemical composition **and** layers
	Accuracy:
	Diagram of layers
	▪ no layers evident
	▪ layers incorrectly labelled **and** some missing
	▪ layers incorrectly labelled
	▪ layers drawn, but some missing
	▪ all layers drawn and correctly labelled
	Graph or chart of chemical composition
	▪ inaccurate proportions and incorrectly labelled
	▪ inaccurate proportions but correctly labelled
	▪ accurate proportions but incorrectly labelled
	▪ accurate proportions and correctly labelled
	Details:
	▪ none
	▪ symbols: **%** / °**C** / other (specify)
	▪ labels
	▪ single words
	▪ phrases or sentences
	▪ in/on layer or chart section
	▪ indicating line
	▪ title
	▪ key/legend
	▪ caption
	▪ other (specify)
	Indications of planning:
	▪ none evident
	▪ tally
	▪ numbering
	▪ margin notes
	▪ highlighting / circling / underlining
	▪ other (specify)

Appendix J

Statistical Tables and Figures

Table J1

Descriptive Statistics for all Grades 6, 7, and 8 Students' Fall School Wide Write (SWW) and District Assessment of Reading Task (DART)

	SWW	DART
Number of cases	415	369
Minimum score	1.0	1.0
Maximum score	4.0	4.0
Range	3.0	3.0
Mean	2.27	2.31
Standard deviation	0.70	0.66
Variance	0.49	0.44

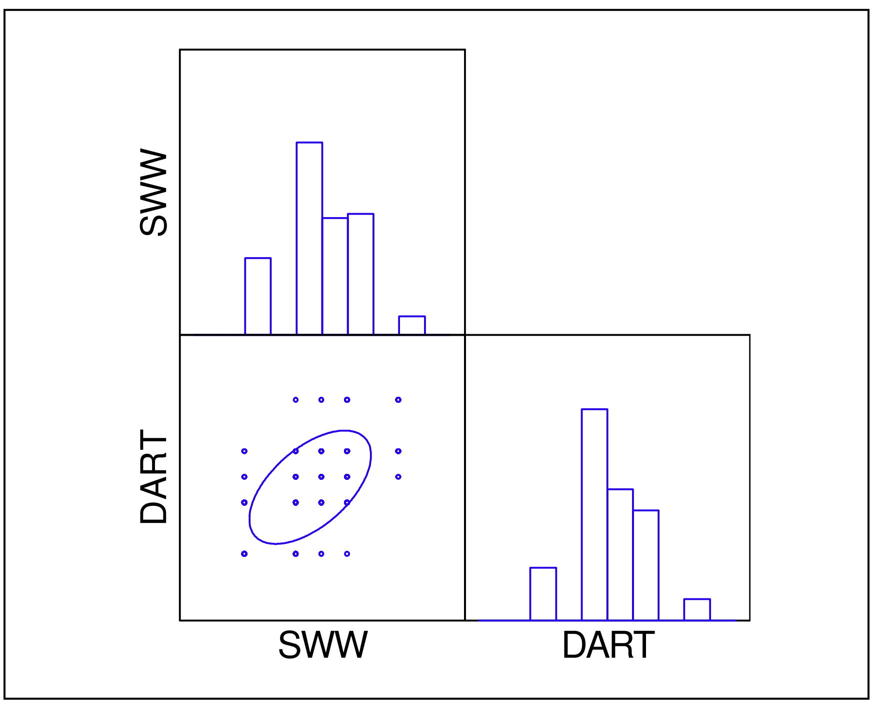


Figure J1. Scatterplot matrix for the fall SWW scores correlated with the fall DART scores for all students at the school.

Table J2

Descriptive Statistics for all Grade 6 Participants' Fall School Wide Write (SWW) and District Assessment of Reading Task (DART) Scores

	SWW	DART
Number of cases	31	31
Minimum score	1.0	1.0
Maximum score	4.0	4.0
Range	3.0	3.0
Mean	2.23	2.27
Standard deviation	0.76	0.53
Variance	0.58	0.28

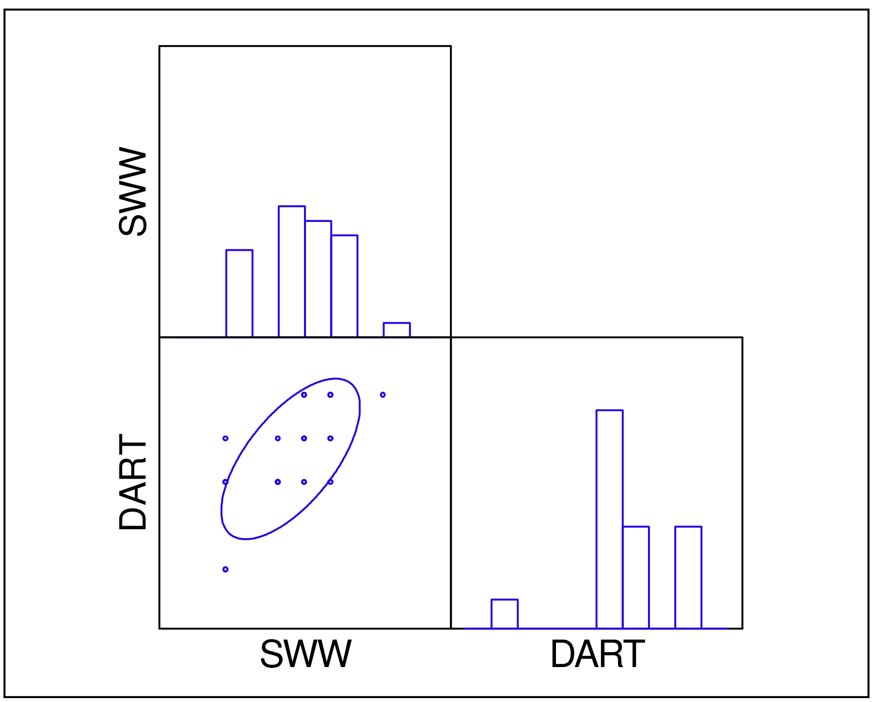


Figure J2. Scatterplot matrix for the fall SWW scores correlated with the DART scores for the Grade 6 participants.

Table J3

Descriptive Statistics, by Class, for Participants' Fall School Wide Write (SWW) and District Assessment of Reading Task (DART) Scores

	SWW		DART	
	Ms. Adams	Ms. Brown	Ms. Adams	Ms. Brown
Number of cases	18	13	18	13
Minimum score	1.0	1.0	2.0	1.0
Maximum score	4.0	2.5	3.0	2.5
Range	3.0	1.5	1.0	1.5
Mean	2.50	1.85	2.53	1.92
Standard deviation	0.75	0.63	0.44	0.45
Variance	0.56	0.39	0.19	0.20

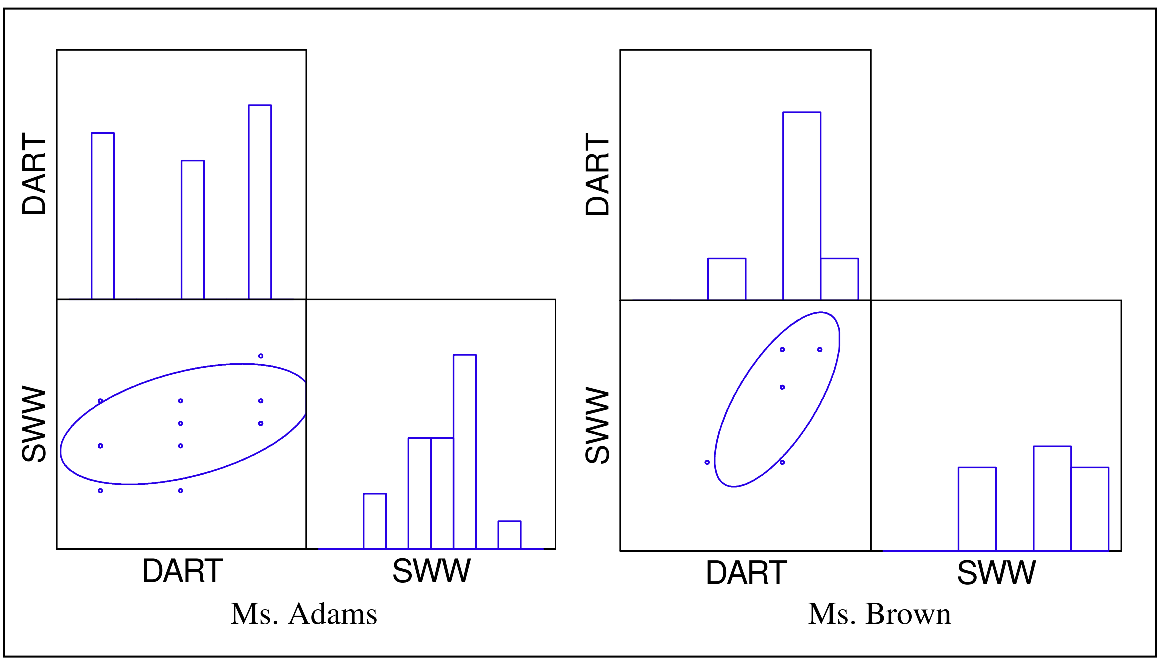


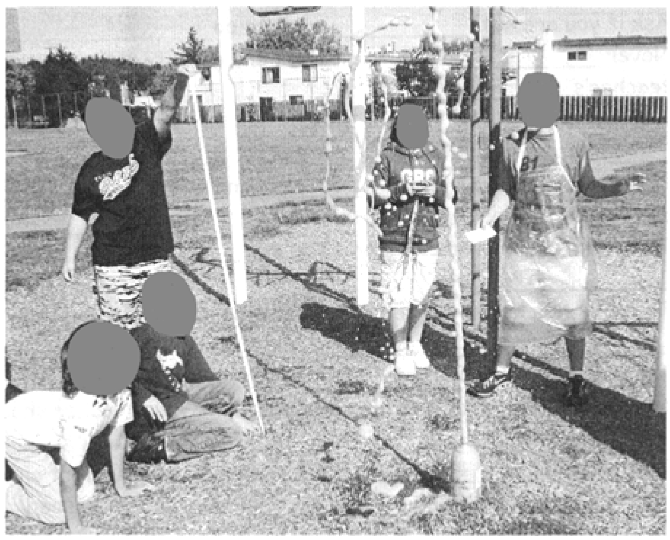
Figure J3. Scatterplot matrices for participants in Ms. Arden's class (left) and participants in Ms. Brown's class (right).

Appendix K

Student Worksheets, Rubrics, and Assignments

Name:____________ Date: ______________

Recognizing Science Safety



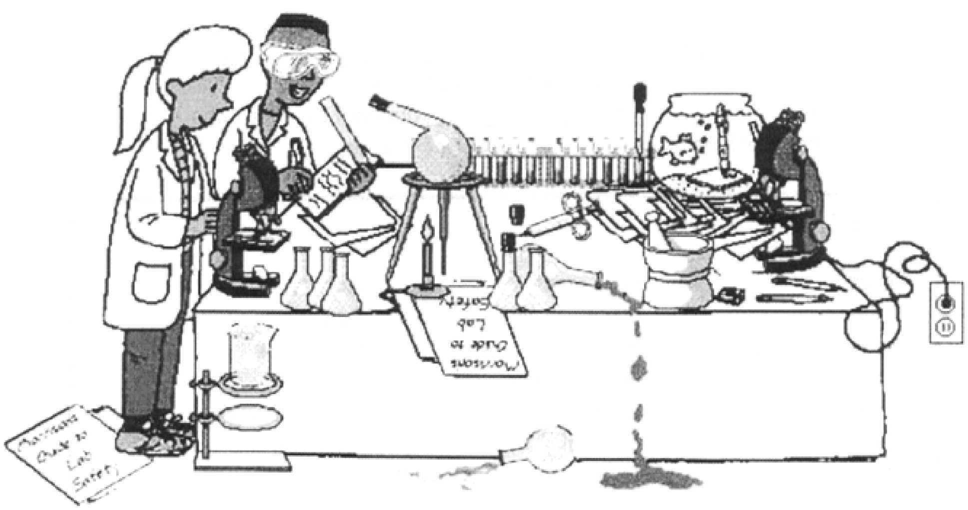


Figure K1. Science safety worksheet.

Date: Name & #:

Experiment: What factors affect plant growth?

Question: How does the amount of energy from the Sun, water, or temperature affect the growth of bean plants?

Hypothesis:

Sunlight: If ______________________________________, then ______
__________________________, because ___________________________
____

Water: If ______________________________________, then ______
__________________________, because ___________________________
____

Temperature: If ______________________________________, then
__________________________, because ___________________________
____

Materials:

Each group will need

- Aprons
- Bean seed
- Pot
- Measuring cup
- Soil
- Ruler

Your group is preparing the bean seed for the following condition:
____

Your group will also need the following materials:

-
-
-
-
-
-

Figure K2. Handout for Ms. Brown's Plant Investigation assignment (p. 1).

Date: Name & #:

Procedure:

All groups will complete the following steps.

1. Put on your aprons
2. Carefully fill your pot with soil, cleaning up any soil that you spill.
3. Using your finger or a pencil, poke a hole about 3 cm deep in the centre of the soil.
4. Gently place the seed in the hole and cover with dirt.
5. Water with ¾ cup of water

Special steps for your condition are:

6. ____
7. ____
8. ____
9. ____
10. ____

Data and Observations:

Sunlight		Water		Temperature	
Dark		Dry		Cold	
Indirect		Moist		Room Temp.	
Bright		Wet		Warm	

Draw a picture that shows the results for your group's variable (sunlight, water or temperature). Include a caption that explains your picture(s).

Figure K2. Handout for Ms. Brown's Plant Investigation assignment (p. 2).

Date: Name & #:

Analysis:

Describe the growth of the bean plant with the least amount of the variable you tested.

____

____

Describe the growth of the bean plant with the most amount of the variable you tested.

____

____

How does the variable you tested affect the growth of bean plants?

____

____

Conclusion:

Look back at your hypothesis. Did your observations support, partly support, or not support you hypothesis? ____

Write a statement that explains the results of your experiment.
The results of my experiment show ____________________________________

____

____

Applications:

How could you use what you learned from this experiment when growing plants at home?

____

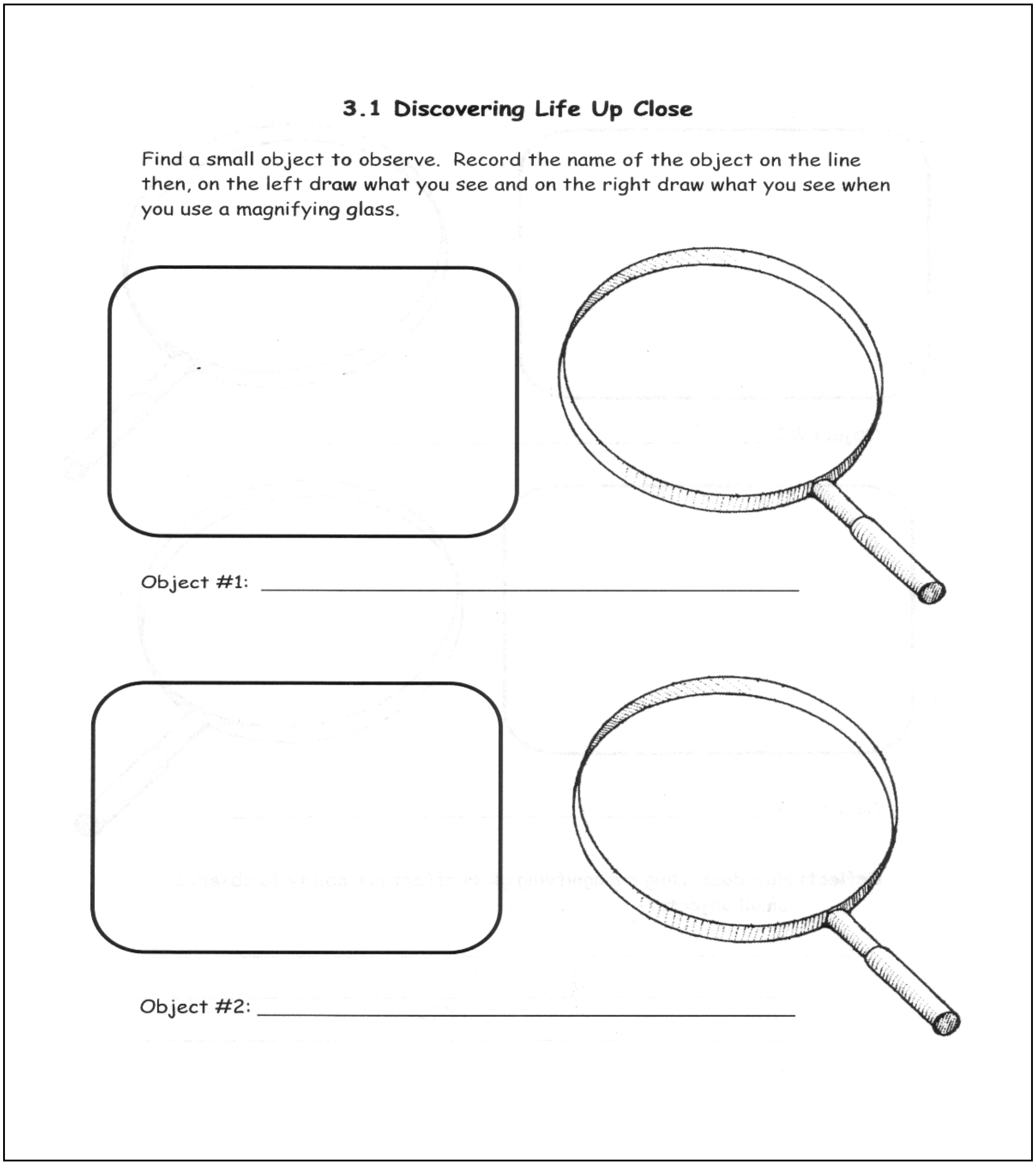
____

Why would your conclusions be important information for a garden store?

____

____

Figure K2. Handout for Ms. Brown's Plant Investigation assignment (p. 3).



3.1 Discovering Life Up Close

Find a small object to observe. Record the name of the object on the line then, on the left draw what you see and on the right draw what you see when you use a magnifying glass.

Object #1: ____________________

Object #2: ____________________

Figure K3. Worksheet emphasizing drawing an object.

Brain POP

Name: ....

Date: ....

TECHNOLOGY > SCIENCE AND INDUSTRY > MICROSCOPES

LABEL IT

Unscramble the letters to spell the different parts of a microscope. Then draw a line connecting each part to its place in the illustration.

PCIEYEEE

....

ALCORUC ESNLSE

....

UOCSF ONBKS

....

MRA

....

UEBT

....

JTIEVEOCB EENLSS

....

GTASE

....

HILTG RCUOSE

....

AEBS

....

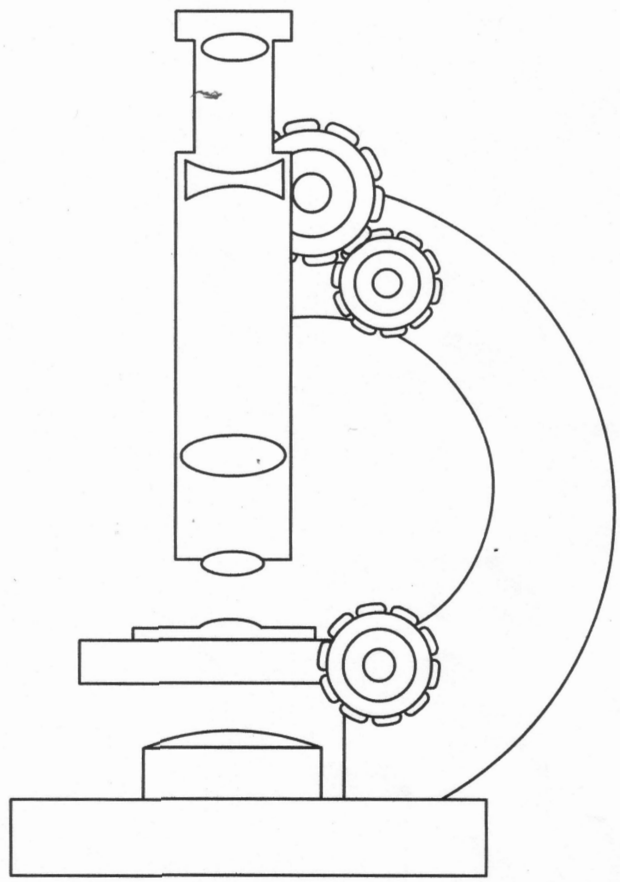


Figure K4. Worksheet emphasizing naming and labelling parts of an object.

Date:

Name:

Part 3: Adaptations

Use the chart below to demonstrate how an **EAGLE** has adapted to meet its needs and survive in its environment.

Type of Adaptation	Give as many examples as you can and how the adaptation helps the EAGLE meet its needs.
Physical	
Behavioural	

Part 4: Labelled Diagram

Turn the picture of the **EAGLE** below into a labelled diagram by adding all of the features we have learned about in class.

Figure K5. Worksheet emphasizing turning a picture into a labelled diagram.

8. What is hibernation? ______________________________

9. Is hibernation a physical or behavioural adaptation? ______________

10. How does hibernation help organisms survive extreme conditions? ______

____

11. What animals hibernate? ______________________________

12. Where do animals hibernate? ____________________________

13. Why is it important for animals to adapt to extreme conditions? ______

____

____

14. Draw a labelled diagram of an imaginary animal that would be well adapted to life in the arctic. Use the caption and labels to explain your animals adaptations.

Figure K6. Worksheet emphasizing creating a labelled diagram.

Date:

Name:
#:

Rubric for 5 Kingdoms Foldable

	Not Yet Meeting		Meeting		Exceeding
Information	Some important information is missing		All required information is included but may not have been expanded Does not include extra information		All required information is included and has been expanded Includes interesting and useful "extra" information.
Picture	Picture does not represent a member of the kingdom Does not have a caption or caption is very short		Picture represents a member of the kingdom Includes a caption that explains the picture Caption may not show an understanding of the kingdom		Picture represents a member of the kingdom Example is unique and not found in the text book. Includes a caption that explains the picture Caption shows an understanding of the kingdom.
Organization Presentation	Late Incomplete Information is not well-organized Messy/rushed - presentation lacks effort Lots of GaPS		On time All major parts complete Information is organized with headings Neat, coloured and attractive lettering Some GaPS		On time Complete with extras Neat & extra effort is evident Organization of information is well thought out and includes headings. Few or no GaPS

Comments:

Figure K7. Rubric for a Foldables® activity that includes creating a picture with a caption.

Date:

Name:
#:

Lab Title ________________________

Rubric for Science Lab

	Not Yet Meeting		Meeting		Exceeding
Hypotheses	Not written in "If…then…because…" format Hypothesis may not be reasonable or shows lack of research/prior knowledge		Written in "If…then…because…" format. Hypothesis is reasonable		Written in "If…then…because…" format. Hypothesis shows evidence of research or strong prior knowledge
Materials/ Procedure	Some materials may not be included Procedure is missing several steps or is very poorly explained.		All materials included Procedure is explained step – by – step. Some steps may be missing or are not clear.		All materials included Procedure is explained step-by-step All steps are included and are clearly explained.
Observations	Labelled diagram is missing or is poorly done Missing qualitative and/or quantitative observations		Includes labelled diagram Has both qualitative and quantitative observations		Includes detailed labelled diagram Has both qualitative and quantitative observations
Analysis/ Conclusions	Answers are missing or too short/unclear Answers do not show satisfactory understanding		All questions are answered Shows a satisfactory understanding of the concepts		All questions are answered clearly Ideas are expanded on to show excellent understanding
Presentation, Completeness & GaPS	Rushed or messy Incomplete lots of GaPS Needs proofreading Late		Neat and complete Some GaPS Needs to be proofread more carefully On time		Neat & carefully completed Extra effort is evident Few or no GaPS On time

Comments:

Figure K8. Rubric for a science lab that includes requirements for a labelled diagram.

Date: Name:
#:

Animal ___________________________

Rubric for **Diversity of Life Poster Project**

	Not Yet Meeting	Meeting	Exceeding
Research	Used less than 3 sources or only 1 type (e.g. internet) Bibliography sheet incomplete or not handed in Notes are in-complete or missing Time provided was not productive Little independent work demonstrated	Used at least 3 sources Including encyclopaedias, books and internet Bibliography sheet complete (minor components may be missing) Notes are complete and organized Time provided was productive Required some assistance/guidance	Used at least 5 sources Including encyclopaedias, books and internet Bibliography sheet is complete and accurate Notes are complete, detailed and well-organized Time provided was very productive Required little assistance/guidance
Information	Some parts incomplete Lacks detail Not enough information Written work is unclear or not in your own words	All parts complete Includes some detail Some ideas have been expanded on Information is presented clearly in your own words	All parts complete Includes detail Ideas have been fully expanded on (very informative) Clear and concise (lots of info without being too wordy)
Diagram	Missing Missing several components	Includes most components taught in class	Includes all components taught in class
Presentation, & GaPS	Rushed or messy Demonstrates lack of effort Lots of GaPS Needs proofreading	Poster is attractive and inviting Somewhat interactive (Foldables etc.) Some GaPS - needs to be proofread more carefully	Poster is very attractive and inviting Very interactive Extra effort is evident Few or no GaPS

Comments:

Figure K9. Rubric for the end-of-unit poster project that includes requirements for a labelled diagram.

Appendix L

Raw Data for Participants' Pre- and Postassessment Representations

Table L1

Raw Data for the Four Evaluations of Participants' Pre- and Postassessment Representations

	Initial rubric score			Number of correct layers			Criterion-based score			Representational competence		
Class	Sun	Earth	Change	Sun	Earth	Change	Sun	Earth	Change	Sun	Earth	Change
Ms. A	3	3	0	3	0	-3	2	3.5	1.5	2	3	1
Ms. A	1	3	2	0	2	2	0	3.5	3.5	1	3	2
Ms. A	1	2	1	0	0	0	1	3.5	2.5	1	2	1
Ms. A	2	2	0	1	0	-1	2.5	4	1.5	2	3	1
Ms. A	5	3	-2	3	6	3	3.5	5	1.5	3	3	0
Ms. A	2	2	0	0	0	0	1	4.5	3.5	2	3	1
Ms. A	3	4	1	2	6	4	1.5	5	3.5	2	3	1
Ms. A	2	2	0	1	0	-1	1	4	3	2	3	1
Ms. A	2	3	1	1	6	5	3	5	2	3	3	0
Ms. A	3	4	1	6	6	0	1.5	3.5	2	2	3	1
Ms. A	2	2	0	0	1	1	1	3	2	2	3	1
Ms. A	3	3	0	0	1	1	2.5	4	1.5	2	3	1
Ms. A	4	4	0	6	6	0	2.5	4	1.5	3	3	0
Ms. A	3	2	-1	5	1	-4	3.5	4	0.5	2	3	1
Ms. A	5	5	0	4	6	2	2	5	3	2	3	1
Ms. A	2	2	0	0	0	0	0	5	5	1	2	1
Ms. A	2	4	2	0	6	6	2	4	2	2	3	1
Ms. A	5	5	0	6	6	0	2.5	5	2.5	2	3	1
Ms. B	4	4	0	6	6	0	3	1.5	-1.5	2	2	0
Ms. B	4	3	-1	6	1	-5	1	2	1	2	2	0
Ms. B	2	2	0	0	0	0	0	3.5	3.5	2	2	0
Ms. B	3	4	1	2	5	3	2	3	1	2	2	0
Ms. B	2	3	1	2	6	4	2.5	2.5	0	2	2	0
Ms. B	3	2	-1	0	1	1	3.5	3	-0.5	3	2	-1
Ms. B	3	2	-1	2	1	-1	2	2	0	3	2	-1
Ms. B	4	3	-1	6	2	-4	1	1.5	0.5	2	2	0
Ms. B	2	1	-1	1	1	0	1	0	-1	2	1	-1
Ms. B	4	4	0	6	6	0	2	2.5	0.5	3	3	0
Ms. B	3	2	-1	1	1	0	2	1.5	-0.5	2	2	0
Ms. B	1	.	.	0	.	.	0	.	.	1	.	.
Ms. B	.	4	.	.	6	.	.	2	.	.	2	.

Appendix M

Connections between the Dissertation Components

	Theme from Verification Study	Literature Review Current Research Themes							Case-to-Case Synthesis Themes					Exploratory Framework Dimensions	
		A	B	C	D	E	F	G	1	2	3	4	5	Meta	SFL
Theme from Verification Study	Strategic planning	☆		☆	☆		☆					☆		☆	
	Selection of information	☆		☆	☆		☆				☆	☆		☆	
	Form and function of representation	☆	☆	☆	☆	☆	☆	☆			☆	☆	☆	☆	☆
	Use of color	☆	☆	☆	☆		☆					☆		☆	☆
	Knowledge of conventions	☆	☆	☆	☆	☆	☆	☆			☆	☆	☆	☆	☆
Exploratory Framework	Meta	☆		☆	☆				☆			☆			
	SFL	☆	☆	☆	☆	☆	☆	☆			☆	☆	☆		
Case-to-case Synthesis	1	☆	☆	☆	☆										
	2	☆		☆	☆										
	3				☆	☆									
	4		☆		☆		☆								
	5		☆		☆										

☆ indicates connection

Figure M1. Connections among the thematic review of the literature and the three components of the dissertation.

A = Learner-generated representation, B = Learning from visual representations, C = Student agency, D = Classroom-based research, E = Assessment opportunities, F = Representational competence G = Static versus dynamic representations; 1 = Multimedia literacy strategies can be engaging and effective, 2 = Multimedia projects facilitate differentiated instruction, 3 = Multimedia projects provide opportunities for assessment, 4 = Visual representations are a key aspect of science instruction, 5 = Literacy strategies can be robust across disciplines; Meta = metacognition, SFL = Systemic Functional Linguistics