Struggling Readers Learning with Graphic-Rich Digital Science Text: Effects of a Highlight & Animate Feature and Manipulable Graphics

by

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Dedication

To Bill, Abby, and Sarah

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I am, as always, grateful to my family. My husband Bill bravely began many car trips, bike rides, and runs through the neighborhood with the question, "So, would you like to tell me about what you are working on now?" And so I did. Abby, who was launching her own career, meticulously and efficiently assisted in the preparation the transcripts for this work and provided useful insights in the analysis of those transcripts. Sarah, who was enrolled in college at the same time as I, provided companionship with just the right balance of earnestness and humor. And John cheerfully and skillfully repaired and refurbished all of those things that I neglected while focused on my dissertation.

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Abstract

Technology offers promise of 'leveling the playing field' for struggling readers. That is, instructional support features within digital texts may enable all readers to learn. This quasi-experimental study examined the effects on learning of two support features, which offered unique opportunities to interact with text. The Highlight & Animate Feature highlighted an important idea in prose, while simultaneously animating its representation in an adjacent graphic. It invited readers to integrate ideas depicted in graphics and prose, using each one to interpret the other. The Manipulable Graphics had parts that the reader could operate to discover relationships among phenomena. It invited readers to test or refine the ideas that they brought to, or gleaned from, the text. Use of these support features was compulsory.

Twenty fifth grade struggling readers read a graphic-rich digital science text in a clinical interview setting, under one of two conditions: using either the Highlight & Animate Feature or the Manipulable Graphics. Participants in both conditions made statistically significant gains on a multiple choice measure of knowledge of the topic of the text. While there were no significant differences by condition in the amount of knowledge gained; there were significant differences in the quality of knowledge expressed. Transcripts revealed that understandings about light and vision, expressed by those who used the Highlight & Animate Feature, were more often conceptually and linguistically 'complete.' That is, their understandings included both a description of phenomena as well as an explanation of underlying scientific principles, which participants articulated using the vocabulary of the text. This finding may be attributed to the multiple opportunities to integrate graphics (depicting the behavior of phenomena) and prose (providing the scientific explanation of that phenomena), which characterized the Highlight & Animate Condition. Those who used the Manipulable Graphics were more likely to express complete understandings when they were able to structure a systematic

investigation of the graphic and when the graphic was designed to confront their own naïve conceptions about light and vision. The Manipulable Graphics also provided a foothold for those who entered the study with very little prior knowledge of the topic.

CHAPTER ONE: INTRODUCTION

JACK'S STORY

Is it possible to use technology to design a reading environment in which struggling readers, interacting with conceptually challenging, graphic-rich science text, can learn as well as their classmates who are typically achieving readers?

Consider the case of Jack, a fifth-grader, and a struggling reader if ever there was one! His word recognition, three standard deviations below the mean for age, was limited to familiar, single-syllable words. On a standardized assessment of reading comprehension he puzzled through the first few sets of paragraphs-plus-multiple-choice questions, but as the length and difficulty of passages increased, he resorted to guessing, scoring in the 1st percentile. His expressive vocabulary was well below norms for age. He spoke infrequently and in short, simply structured sentences punctuated by expletives: Cool! Holy moly! Dang!

Jack agreed to participate in a study of how fifth graders learn from conceptually challenging, graphic-rich science text. The text for this study was presented in a digitized (computer) environment and embedded with experimental features designed to support readers to interpret and integrate the verbal and visual messages of the multimedia text. Things got off to a rocky start. The first day of the study began with a multiple-choice pretest of knowledge about light and vision – the topic of the experimental text, *How Do We See.* Though the test was read to him, Jack answered only two out of nine questions correctly. He seemed aware of, and agitated by, his limited knowledge of the topic of the test. When the pretest of content knowledge was followed by a difficult word recognition assessment, Jack pronounced the activities **"stupid!"** He swept the table clear of the frustrating materials as he stalked out of the room. The next day, accepting an invitation to try again, Jack explored the digital reading environment. He jabbed with gusto at the computer keyboard, shutting down the program several times. **"Cool,"** he said, **"I want to do more."** He did much more. Jack examined the illustration on the first screen. A young explorer in an illuminated cave gazed up at stalactites (see Figure 1.1). Jack stated what he saw in the illustration, **"helmet. Uhh… he looking at, he's in a cave. Looking at moon."**

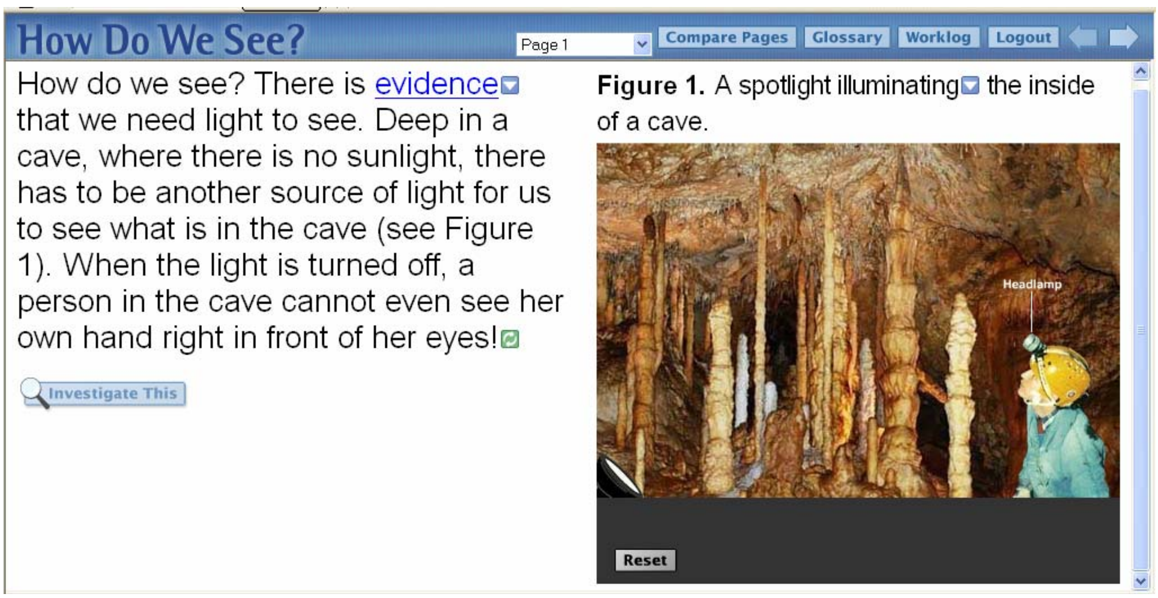

Figure 1.1
Page 1 of the experimental text *How Do We See*

Jack declined an offer to have the computer read the text aloud to him. His reading of the introductory material was labored:

Jack: When the light is turned on…

Interviewer: Off.

Jack: Off a …

Interviewer: Person.

Jack: Person in the cave cannot…

Interviewer: Even.

Jack: Even see her…

Interviewer: Own.

Jack: Own right hand in…

Interviewer: Front.

Jack: Front of her eyes.

When he finished reading he turned his attention to opportunities to explore the information on the page in more detail. **"What the heck is that word?"** He aimed and fired his cursor at the synonym tool next to 'evidence,' producing its synonym: 'proof.' Next he activated the **Highlight & Animate** Feature. He studied the screen closely as the computer highlighted in yellow the important sentence 'a person in the cave cannot even see her own hand in front of her eyes' and simultaneously animated the graphic, making the cave go dark, consistent with the information in the highlighted message (see Figure 1.2). He was impressed with the results, **"Oh my God. I can. Hey!"**

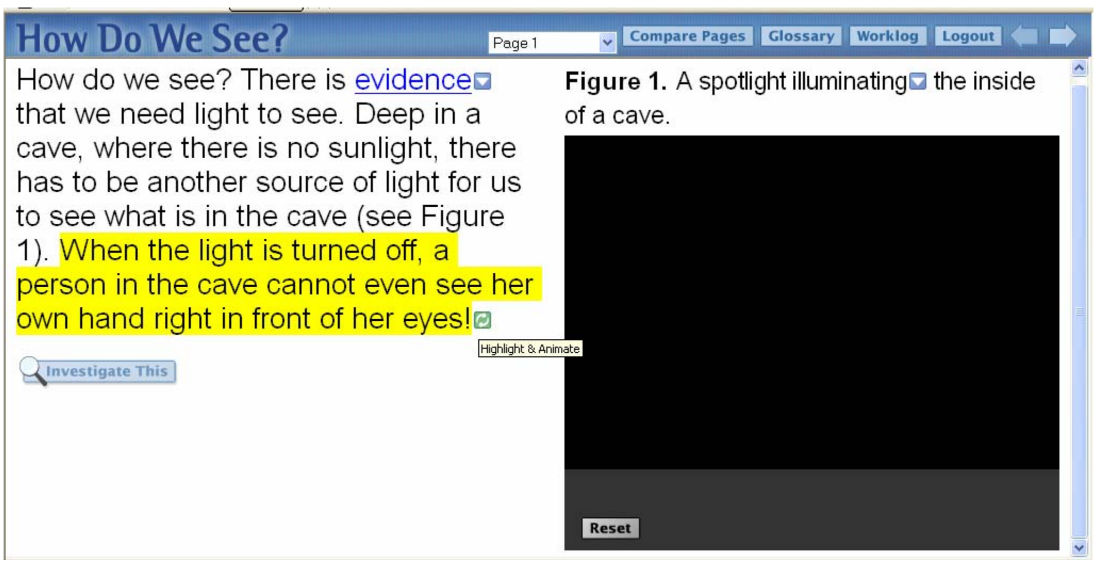

Figure 1.2
Page 1 with Highlight & Animate Feature activated

He moved on to investigate the ideas of this page by means of a **Manipulable Graphic**. Jack repeated the 'Directions to Investigate' after the interviewer, who read them aloud. Then he moved the headlamp slider right and left, as recommended, a number of times, observing the effects of different amounts of light – or no light at all – in the cave (see Figure 1.3). Jack spontaneously narrated the events of his investigation:

Interviewer: Directions. It says, ‘to change the beam width of the caver’s headlamp, drag the headlamp slider.’

Jack: Headlamp. Slider. Turn off. Go, turn off. Did that.

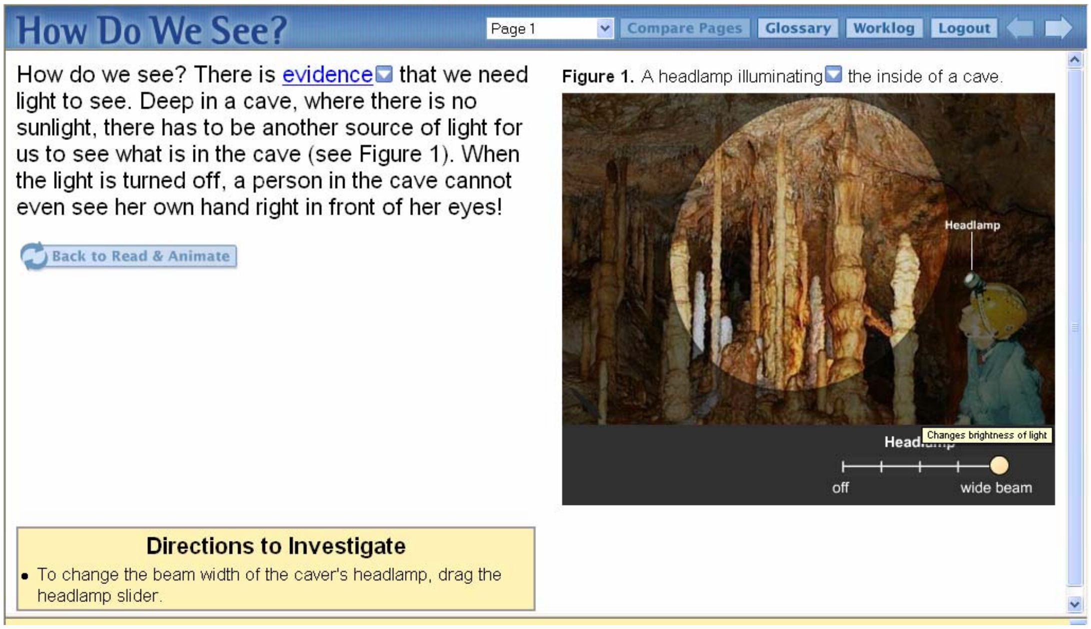

Figure 1.3
Page 1 with Manipulable Graphic activated

Then, in response to several open-ended questions, he described and demonstrated with the Manipulable Graphic what he had seen during his investigation:

Interviewer: So tell me, what did you observe?

Jack: The light is getting smaller. To off.

Interviewer: Is there anything you want to add?

Jack: And the light is getting bigger. See?

The interviewer typed Jack’s response in a work log and reviewed it with Jack. Jack was impressed with the volume of written material he had produced, but critical of the interviewer’s transcription. Jack concluded his interaction with the first page of *How Do We See* by spontaneously coordinating his observations of what happened when he animated the graphic (the headlamp could be turned off) with information gleaned when he read the prose (the caver could not see his hand when the headlamp was turned off).

> **Jack: That's a lot. Holy Moly! You put three E's.**
> Interviewer: Sorry. Thank you. Anything else?
> **Jack: The light, the light is off and he cannot see his hand in front of his face. It said that. Right there.**

In this way Jack read all eight pages of *How Do We See*. He continued to provide evidence that he was engaging in activities to develop his own understanding of the text in several ways. He described what he saw in the graphics **("nerve is holding the eyeball, it doesn't fall out"),** identified and adopted unfamiliar words (iris, observe, reflect) after looking up their meanings, investigated the graphic by manipulating its changeable features, narrated his activity while investigating, and commented on what he already knew and what was new to him **("that's true," "didn't know that," "goes to the brain – did that yesterday").**

On the posttest of knowledge about light and vision Jack followed along on the printed page as the first multiple-choice question was read to him. To the first two possible (but incorrect) responses, he growled **"nahhh"** and dismissed them with an abrupt gesture of his hand. Mid-way through the third (correct) answer he banged his fist on the table and announced **"Yeah!"** In this manner he responded to all nine questions – perfectly! Of the seventy-three participants in this research, only one other, a very skilled reader, got every item correct on the posttest.

Is it possible to create an environment in which struggling readers can successfully build knowledge from a conceptually complex, multimedia science text? For this struggling reader the answer was a resounding **"Yeah!"** Jack's responses to the posttest as well as his spontaneous remarks and answers to the interviewer's questions indicated that his work with *How Do We See* in the digitized environment produced a solid understanding of ideas about light and vision that he had not been able to demonstrate on an earlier pretest. Other struggling readers who participated in the same study demonstrated learning as well. In fact, the digital environment of this study “leveled the playing field.” Struggling readers gained as much knowledge of concepts of light and vision as their classmates who were typically achieving readers (Dalton et al., 2006).

GENERAL CONTEXT OF THIS STUDY

Why is it important that this small group of struggling readers was able, with the aid of an experimental technology, to demonstrate average yet substantial gains in learning from a grade-level text? Because there are so many more students very much like them. In fact, there are 8.7 million students in U.S. schools who are unable to understand their textbooks (Kamil, 2003). Thus, they gain only limited access to important concepts of the academic curriculum and the benefits that accrue to those who master them. There is an urgent need to develop interventions that are effective in supporting these students to learn from their textbooks.

Students’ difficulty in reading to learn from their science textbooks is, in part, attributable to domain-specific properties of those texts. Texts in the complex domain of science are composed of multiple (external) prose and graphic representations. Thus, learning from those texts requires that the reader create and synthesize multiple (internal) mental representations (Goldman, 2003). This can be a daunting task for the developing reader just beginning formal study of science. The reader must understand the domain-specific vocabulary and the complex syntactic and semantic relations of the prose (Schleppegerell, 2002), interpret a vast array of unfamiliar graphic images (Lemke, 2002), and integrate information from these interdependent sources to understand concepts that challenge the reader’s own established ideas about how the world works (Selley, 1996b, Lemke, 2004). It is the facilitation of readers’ interpretation and integration of information from prose and graphics, required to form cohesive mental representations of the ideas of science text, which is the subject of this study.

Efforts to support struggling readers to integrate the multiple representations of science text are timely, given trends in educational standards, research in reading comprehension, and developments in instructional technology. Educational standards now require that all students, including low-achieving readers, master the general academic curriculum (No

Child Left Behind, 2001) and engage in critical thinking with texts in complex domains like science (National Research Council, 1996). Increasingly, materials used to address these instructional objectives include graphic-rich static texts and multi-media web-based resources (Coiro & Dobler, 2007; Lemke, 2004). Literacy researchers are now attending to the domain-specific nature of comprehension of content area texts, arguing, for example, that in order to learn from science text readers must think and communicate as scientists do about the big ideas and organizing principles of the discipline (Morocco, 2001; Palincsar, 2005). Technological innovations show promise to support readers to construct meaning from challenging content area texts, and science texts in particular, by making reading strategies more explicit and visual images more interactive (Dalton et al., 2006; Dalton & Proctor, 2007; Johnson-Glenberg, 2007; McNamara, O'Reilly, Rowe, Boonthum, & Levinstein, 2007; Meyer & Wijekumar, 2007). And, textbook publishers, in compliance with the National Instructional Materials Accessibility Standards (NIMAS), now must provide electronic versions of new textbooks that may be enhanced to make text accessible for students with print disabilities (Center for Applied Special Technologies, 2008; National Center for Supported Electronic Text, 2007).

While considerable research has attended to supporting upper elementary readers to understand the prose of their science textbooks, somewhat less attention has been accorded to guiding these readers to interpret graphics, and very little research has focused explicitly on the integration of prose and graphics. The research is particularly lean with respect to struggling readers in the upper elementary grades, who, as novices to the complex domain of science, are most in need of scaffolding to support their learning. What very little research there is suggests that upper elementary readers fail to effectively integrate the multimedia messages found in their science texts (Dalton & Palincsar, 2004; Moore & Scevak, 1997).

SPECIFIC CONTEXT OF THIS STUDY

One program of research that addressed the integration of prose and graphics to facilitate learning with upper elementary science text was conducted by Dalton and Palincsar

(2004, Dalton et al., 2006)[1]. This program of research on reading comprehension was entitled *Reading to Learn: Investigating general and domain-specific supports in a technology-rich environment with diverse readers learning from informational text*. In the first phase of the *Reading to Learn* work, or the 'Think-Aloud Study,' investigators used think-aloud protocols to study the text processing of fourth graders reading graphic-rich, digitized science text. One-half of the 43 participants were struggling readers; one-half were typically-achieving readers. Investigators discovered that although the static graphics served as a point of entree´ to a conceptually complex text, few participants integrated the complementary information in prose and graphics. Those few whose think-alouds suggested that they did attend to both prose and graphics, mostly typically achieving readers, demonstrated modest gains in knowledge of the topic of the text.

The second phase of the *Reading to Learn* work was the 'Intervention Study,' the study in which Jack participated. In the Intervention Study, 48 fifth-grade participants (including 12 struggling readers) read a challenging, graphic-rich, digitized science text – *How Do We See* – with the support of two experimental features embedded in the digitized environment: a Highlight & Animate Feature and Manipulable Graphics. These features were designed to facilitate in unique but complementary ways, readers' interpretation and integration of graphics and prose. The Highlight & Animate Feature simultaneously highlighted important ideas in the prose and animated a corresponding representation in the graphic. The Manipulable Diagrams allowed participants to conduct an investigation by changing selected aspects of the graphic. Twenty-four additional participants, serving as a control group, read *How Do We See* without the Highlight & Animate Feature or the Manipulable Graphics. They had only static graphics. The findings, illustrated by Jack's story at the outset of this chapter, were that the participants who used the digital environment with the Highlight & Animate Feature and the Manipulable Graphics demonstrated significant gains in knowledge of the topic of the text. Furthermore, this intervention 'leveled the playing field' so that struggling and typically achieving readers made comparable gains.

[1] The primary investigators were Bridget Dalton, Ed.D., of the Center for Applied Special Technology, Wakefield, Massachusetts, and Annemarie Palincsar, Ph.D., of the University of Michigan, Ann Arbor, Michigan. This work was funded by the Institute for Education Sciences.

In my role as an interviewer, working one-on-one with participants in the Intervention Study, I saw that though struggling readers as a group performed well, there was considerable variation in knowledge gained across participants. For example, Jack entered the study with pretest scores indicating minimal knowledge of the topic of the text and exited the study with a perfect posttest score. Mike entered with similarly low knowledge scores and, in spite of much better word recognition and receptive vocabulary skills than Jack, lost ground on the posttest. I sought to understand this variation in struggling readers' learning: did the experimental features – the Highlight & Animate Feature and Manipulable Graphics – mediate learning and if so, how? This understanding could provide insight into the challenges that a graphic-rich science text presented to struggling upper elementary readers as well as ideas to guide the design of future instructional interventions and environments to support struggling readers to learn from graphic-rich science text.

The Highlight & Animate Feature and the Manipulable Graphics each offered different affordances for interacting with the ideas of the text. However, in the context of the Intervention Study it was impossible to ascertain what unique contributions either of these features made to participants' learning since: (1) all participants had access to both features, which made it difficult to distinguish readers' responses to either feature, (2) participants used the features inconsistently, perhaps not recognizing instances of their own limited understanding or the potential utility of the features in supporting their developing understanding, (3) participants usually preferred the Manipulable Diagrams, hurdling quickly over the prose and the Highlight & Animate Feature to get on to the more engaging investigation, and (4) data from pre-post tests revealed how much participants learned, but not how they learned. A different design would be required to study the separate contributions of each experimental feature. Thus, this dissertation research was designed to extend the *Reading to Learn* program of research by conducting a study of fifth-grade struggling readers' interactions with the affordances of the experimental features.

The purpose of this ‘Study of Experimental Features of an Electronic Text’ was to discover if, and how, the Highlight & Animate Feature and the Manipulable Graphics contributed to variation in struggling readers’ interaction with the digital environment and their understanding of the ideas of the text. This Study of Experimental Features adopted a design in which (1) the participants used <u>only</u> the Highlight & Animate Feature <u>or</u> the Manipulable Graphics so that the effects of each feature could be studied separately and without readers developing a preference for one feature, (2) participants’ use of the features was <u>compulsory</u> at each opportunity signaled in the text in order to examine participants’ responses to these features when used consistently, and (3) the researcher conducted both quantitative analyses of pre-post assessments to see <u>what</u> participants learned and qualitative analyses of spontaneous moves and interview-elicited comments to see <u>how</u> participants developed and articulated understanding as they interacted with the text using the experimental features.

One additional element of the design of the study, relevant to the discussion of earlier studies in this program of research, should be noted here. There was no control group (i.e., participants who either read the text without the experimental features, or for whom use of the experimental features was optional). Findings from both the Think-aloud and Intervention Studies had already revealed some of what might be learned from control groups. For example, they showed that upper elementary struggling readers learned little when they read a text that was very similar (Think-aloud Study) or identical (Intervention Study) to *How Do We See*, but without the support of the experimental features. And, observations of participants in the Intervention Study revealed that without explicit instructions to activate the experimental features, some readers would not use them spontaneously.

To summarize, the research to be described here examined fifth-grade struggling readers’ interactions with a graphic-rich, digitized science text to discover:

> What were the effects of a Highlight & Animate Feature and Manipulable Graphics on participants’ knowledge of the topic of the experimental text?

How did the Highlight & Animate Feature and Manipulable Graphics mediate participants' interactions with the experimental text?

The design of this study was informed by theoretical and empirical work in the areas of research on the reading comprehension of struggling readers, the conceptual, linguistic, and graphic characteristics that make science text challenging for upper elementary students, and the developments in technology that can be used to support learning from challenging texts. This literature will be discussed in more detail in the following chapter.

CHAPTER TWO: LITERATURE REVIEW

The purpose of this literature review is to set forth the theoretical ideas and research findings that are important as they informed the choices made in the design (of goals, research questions, methods, and validity concerns), conduct, and interpretation of this study. The purpose of the study was to examine the efficacy and the affordances of two features, built into a digital environment, designed to support upper elementary struggling readers to learn from multimedia science text. Specifically, this literature review will address three topics relevant to that purpose: 1) What are component skills of the reading process that must be supported if struggling upper elementary readers are to comprehend their textbooks? 2) What characteristics of science text should be considered in designing interventions to support comprehension of science text? 3) How have technological tools evolved to support upper elementary readers' learning from complex, informational text? This review begins with a discussion of the challenges that struggling readers encounter in their efforts to learn from the informational texts of the upper elementary curriculum.

Attending to Component Reading Skills

There is a sense of urgency regarding the needs of struggling readers at the upper elementary level. The numbers alone are compelling. Nationwide, in 2006, 38% of 4th graders scored "below basic" in reading (National Center for Educational Statistics, 2006). The diversity of their instructional needs is daunting. Buly and Valencia (2002) identified ten markedly different profiles of strengths and limitations among upper elementary readers who failed a statewide reading assessment. Recognizing who these struggling readers are can be problematic. Some 'late-emerging poor readers' who appeared to be reading satisfactorily in the lower grades, encounter significant reading comprehension difficulties at the upper elementary level as texts become more challenging (McGuinness, 2005; Scarborough, 2005). Yet, these struggling readers are in a critical period with respect to academic achievement, when it is important to identify their difficulties and intervene as soon as possible. Now, more than ever, they are expected to read to learn from informational text with its unfamiliar text structures and demands for domain-specific literacy skills (Biancarosa, Palincsar, Deschler, & Nair, 2007; Snow, Griffin, & Burns, 2005). It is important to develop interventions that are powerful enough to support struggling readers to learn how to learn from these texts.

Research provides information about struggling readers and reading processes that can guide the design of interventions to support readers' learning from informational text. Of primary importance is knowledge of how readers build representations from what they read by means of higher-level processes of strategic comprehension and metacognition. Other component skills essential to reading include basic processes of fluent word recognition and vocabulary acquisition. Each of these components will be discussed briefly with respect to considerations that are relevant to this study. It is important to note at the outset of this discussion that the ways in which each of these components functions as a relative strength or liability varies widely across struggling readers (Buly & Valencia, 2002). An overriding theme in this literature is that all readers have limits on the amount of cognitive resources that may be allocated to the task of learning from text; the challenge for struggling readers is to allocate those resources to components of the reading process in the most productive manner.

COMPREHENSION AND METACOGNITIVE PROCESSES

The cognitive processes of comprehension and metacognition enable readers to understand and to learn from text. van den Broek and colleagues (Kendeou & van den Broek, 2005; van den Broek, Virtue, Everson, Tzeng, & Sung, 2002; van den Broek, Young, Tzeng, & Linderholm,1999) have developed a model of these processes, the 'landscape model,' which provided the theoretical underpinning that informed this dissertation study. In the landscape model the product of successful reading is a coherent mental representation of a text. This representation is gradually built from information activated as readers proceed through text. Information comes from several sources – the immediate segment of text, preceding segments of text, and background knowledge. Readers selectively allocate their limited attentional resources to those information sources most necessary to engage in cognitive processes which, potentially, will advance their understanding of the text. Cognitive processes, or strategies, include inferring, elaborating, explaining, summarizing, paraphrasing, and integrating information. Readers engage in metacognitive processes as well, continually evaluating their evolving representation of the text against their own standard for coherence. When their representation does not meet their standard for coherence, that is, when they do not understand the text, they may take corrective action. It is important to note, since this dissertation study concerns graphic-rich text, that the authors describe the landscape model of text processing as applicable to static and animated (studied in television programs) images, as well as written prose.

Individual differences in the accuracy and coherence of the mental representation, can be attributed in part to differences in readers' repertoires of strategic processes to facilitate comprehension or their ability to transfer these strategies to other contexts, as well as differences in standards for coherence and in background knowledge (van den Broek, Kendeou, Kremer, Lynch, Butler, White, & Lorch, 2005). Struggling readers use fewer different types of strategies and use strategies less frequently as text becomes more difficult (Kletzien, 1991). Even struggling readers who use strategies that facilitate text-level coherence in narratives (e.g., offering an explanation of a character's motivation) are often limited to strategies that address proposition-level understanding (e.g., paraphrasing a sentence or defining an unfamiliar word) in informational text (DeFrance, 2004). It may be that struggling readers, many of whom have language processing difficulties, expend so much of their information-processing resources on interpreting individual propositions, that they have few resources left for building text-level representations. The intervention reported here was designed to support readers' construction of coherent representations of text by investigating and integrating the ideas presented in prose and graphics.

Ideally, readers would set standards for coherence that demand a thorough understanding of a text. Struggling readers' understanding of text may be constrained by limitations in knowledge and/or application of metacognitive skills (Paris, 1991). Compared to their typically reading peers, struggling readers may demonstrate limited knowledge of actions they can take to facilitate comprehension, poor monitoring of their own comprehension, difficulty evaluating the requirements of a text to set goals for reading, or poor insight into their own needs as a reader, which is necessary to match comprehension processes to the reading task (Dickson, Collins, Simmons, & Kameenui, 1998). There were several metacognitive components to the intervention reported here. In preparation for reading the text, participants were provided with orientations to the digital environment that included a hands-on demonstration of the experimental features and explicitly stated descriptions of how the features were designed to assist their learning. The Manipulable Graphics of this current study were designed to prompt participants to compare their own thinking with the ideas in the text. Outcome measures for the current study included a metacognitive component in the form of interviews that elicited participants' reflections on how they learned in the digital environment.

WORD RECOGNITION AND WORD KNOWLEDGE

Reading comprehension is dependent, in part, upon word recognition, or the association of a printed word with its meaning (Chard, Simmons, Kameenui, 1998). In typical readers, word recognition becomes increasingly rapid and automatic through the early elementary years. By contrast, for many struggling readers, recognition of even familiar words remains slower and requires more conscious processing well into the upper elementary years (Perfetti, 1985). Stanovich (2000) explains how poor word recognition interferes with reading comprehension. Lacking an efficient means of word recognition, the struggling reader must devote considerable cognitive resources to this basic process, leaving fewer resources to dedicate to the higher-level comprehension processes required to learn from text. It was a priority of the intervention reported here to enable participants to devote as many of their cognitive resources as possible to making sense of the text. Thus, support for word recognition was provided in the digital environment of the present study.

Initial understandings of text are constructed by combining individual words into propositions (Kamhi, 1991). Thus, comprehension of text depends on readers' knowledge of the words that make up the text. Vocabulary knowledge can be measured in terms of breadth, or quantity of words in one's mental lexicon, and depth, or quality of nuanced understandings about those words (Beck & McKeown, 1991; Wagner, Muse, & Tannenbaum, 2007). By any measure, struggling readers tend to have less vocabulary knowledge than their typically reading peers (McGregor, 2004). In the upper elementary grades, where words are learned mostly incidentally, in the context of reading, struggling readers have difficulty using context to efficiently acquire the knowledge of new words they need to understand their texts (Beck, McKeown, & Kucan, 2002). Yet, content area reading makes heavy demands on vocabulary skills as it employs words that are new labels for familiar concepts, new, discipline-specific meanings for familiar words, and words that embody new concepts (Blachowicz & Fisher, 2000). Vocabulary demands specific to the domain of science will be discussed later in the portion of this literature review devoted to the linguistic characteristics of scientific communication. In view of research that finds vocabulary knowledge to be both critical to comprehension of content area text and a potential stumbling block for struggling readers, the intervention reported here provided vocabulary support specific to the text participants were reading. Measures of receptive and expressive vocabulary specific to the text served as one of several indices of learning in the study reported here.

These component skills –comprehension strategies and metacognition, word recognition and vocabulary – define both resources that struggling readers bring, and areas in which they may require support, in order to make sense of text. Struggling readers' sense making also hinges, in part, on another important consideration – the characteristics of the text. This literature review now turns to a discussion of the characteristics of science text in general and to the features of the experimental text in particular.

Understanding Scientific Reasoning and Communication

This dissertation study was designed using the context of a science text because making sense of science text can be difficult for upper elementary students who are certainly novices to the domain of science. They have had little experience with scientific disciplines. They have not had opportunities to acquire much of what Schwab (1964) refers to as *substantive knowledge,* or the received interpretation of phenomena. Rather, in the course of their everyday experiences novices have developed their own intuitive conceptions which are only are partially compatible, sometimes even incompatible, with formal models (Langley, Ronen, & Eylon, 1997). Moreover, they have not yet developed the *knowledge of syntactic structures* (Schwab, 1964), the discipline-specific inquiry and reasoning processes of generating and interpreting evidence to test scientific claims that practitioners use to produce substantive knowledge by. Novices interpret the scientific phenomena of their everyday experience with common sense reasoning rather than the scientific reasoning of the discipline and of their texts.

Three characteristics of science text, of particular relevance to this study, account for some of the challenges that novices encounter. These characteristics are the conceptually demanding nature of the knowledge to be constructed, the linguistically complex way in which ideas are communicated, and the array of relatively unfamiliar, domain-specific graphics to be interpreted. The literature review that follows highlights research regarding the pivotal nature of each of these characteristics in upper elementary readers' comprehension of science text. Examples specific to the conceptual demands of the topic of light and vision (the topic of the experimental text of the present study), the linguistic structures, and the graphic images of the experimental text show each of these characteristics in the context of the intervention reported here.

The conceptual, linguistic, and graphic challenges of science text not only define the setting of this research, but figure prominently in the design of the experimental features – the Highlight & Animate Feature and the Manipulable Graphics – and in the analysis of participants' responses to those features. The reasoning behind the design of these tools is this: the language and graphics of science text are uniquely well-suited to their individual purposes in communicating conceptually challenging scientific ideas. Graphics demonstrate quantities, nuances, and relationships among phenomena, especially phenomena not easily available to perception (Lemke, 2002). Specialized language forms communicate the scientific interpretations or beliefs about phenomena of the physical world in terms that reveal both what scientists do and how they reason (Halliday, 1993).

Language and graphics are also complementary, each supporting interpretation of the other. Graphics depict phenomena whose characteristics are not easily explained in words; language provides explanations which cannot be intuitively derived from graphic depictions. Thus, scientific understanding is best achieved by the integration of complementary prose and graphics (Lemke, 2000). There is evidence, reported in the introductory chapter of this dissertation, that novices, particularly those who find the prose or graphics inaccessible, do not take sufficient advantage of the complementary nature of ideas from the prose and graphics, nor do they spontaneously integrate those ideas (Palincsar et al., 2004). The experimental features of the present study were designed to support readers to construct coherent representations of abstract concepts by interpreting and integrating prose and graphics. Analysis of readers' interactions with the experimental text of the present study asked if there were evidence that readers' use of the experimental features facilitated their interpretation of ideas in the prose or their reasoning about phenomena shown in the graphic.

CONCEPTUAL CHALLENGES

A well-established principle of learning is that "new knowledge must be constructed of existing knowledge" (Bransford, Brown, & Cocking, 2000, p. 10). Theories of reading comprehension assign a central role to readers' own knowledge in their construction of meaning from text (Anderson, 1984; Graesser, 2007; Kintsch, 1998). Readers who have rich, organized, domain-specific knowledge which they can access easily and integrate with information from text are well-equipped with the expertise needed to learn, that is, to construct robust mental representations of text (Best, Rowe, Ozuru, & McNamara, 2005). The knowledge that upper elementary readers bring to the study of science is that of novices. It usually includes partial understandings, common sense explanations (or 'naïve conceptions') generated in the course of their everyday experience and perceptions of phenomena in the world (Driver, 1989; Eaton, Anderson, & Smith, 1984).

Knowledge of Concepts of Light and Vision. The difficulties that upper elementary readers have in developing scientific conceptions of light and vision, the topic of the text used in this study, are due in part to interference from their own firmly established common sense explanations and, in part, to the failure of text to anticipate and address these conflicting ideas (Langley, et al., 1997). Galili and Hazan (2000) speak to the conceptual obstacles encountered when using everyday experience to construct an explanation for optical phenomena, and the ways in which novices' own explanations of these phenomena must be considered when designing instruction to facilitate their understanding of scientific explanations. Our understandings of light are limited by the senses we use to perceive it, since the physical parameters of light are not available to human perception. For example, one cannot sense its speed, in fact, it seems stationary. Characteristics that can be perceived may actually be the effects of the air through which we view light, and not representative of the behavior of light. An example is the glow around a light source.

Language developed to describe light-related phenomena on the basis of human perceptions (e.g., objects 'shine') is not consistent with scientific explanations of it. Students spontaneously explain phenomena in terms of logical, cause and effect relationships. These logical explanations are context-specific, developed to suit particular instances. The result is 'knowledge in pieces' (DiSessa, 1993) that lacks the coherence and organization of scientific thought. Further, these logical but speculative explanations, based on appearance as described above, are likely to be incorrect and incompatible with scientific explanations provided in a text.

Fortunately, upper elementary students' understanding about light and vision is a topic that has been sufficiently researched so that the text written for this study could anticipate – and confront – some of the naïve conceptions that readers would bring. Researchers have used multiple choice formats, open-ended oral and written questions, drawing, and discussion, to elicit children's pre-instruction notions of how light helps us see (Cottrell & Winer, 1994; Eaton, et al., 1984; Osbourne, Black, Meadows, & Smith, 1993; Selley 1996a; Selley, 1996b; Shapiro, 1994; Winer, Cottrell, Kerefilaki, & Chronister, 1996). Invariably a product of these investigations is a model that includes an object such as a tree, a light source like the sun, and a person facing the object. Arrows drawn or selected by the child indicate the path and direction of light. Some models are augmented by a child's explanation, either spontaneous or in response to prompts or challenges from the interviewer. Though methodologies are diverse, this research consistently reports a common set of pre-instruction ideas about light and vision that children aged 9-11 years, may hold. Three examples of these ideas, organized around fundamental concepts about light and vision (Heywood, 2005), are presented here.

We need light to see. The first example: concerning the concept that we need a source of light to see. Children know from their own experiences *that* they need a source of light to see, but they seldom know *why* this is so (Selley, 1996b). Some upper elementary students may think in terms of a 'pool of light' (see Figure 2.1 a), emphasizing how light *helps* vision by brightening or bathing things with light (Eaton, et al. 1984; Heywood, 2005). They may not understand that it is the behavior of light, reflecting an image, rather than the illuminating property of light that is important. They talk in terms of the behavior of a person, who must take the action of looking in order to see (Langley, et al., 1997; Selley, 1996a).

Light is reflected from objects. The second example: regarding the concept that light travels from a source to an object and is reflected. The concept that light is reflected from objects is highly context-dependent (Langley et al., 1997; Selley, 1996b). Fifth graders can usually see that a luminous object such as a candle or glowing stick would emit light, but find it implausible that a non-luminous object such as a piece of paper can also reflect light. However, most fifth graders have a notion that something, described as light rays or beams or vision, travels between the object and the eyes. But, the idea of something traveling between eye and object must be reconciled with their thinking that vision is an active process. So, they reason that the direction of travel is from eye to object, since the person must have initiated the action by looking. The idea that a person emits something through the eyes is called "emission." The simple emissions model consists of a single path, eye to object (see Figure 2.1 b). Fifth graders often subscribe to a more complex, dual emissions model, the most prominent of which includes an additional path from light source to object, lighting up the object in cooperation with the visual ray as both rays meet at the object (see Figure 2.1 c). For many, this model of vision remains stable through adulthood.

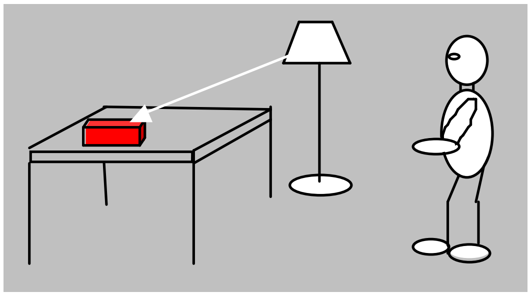

Figure 2.1.a   Pool of light model.

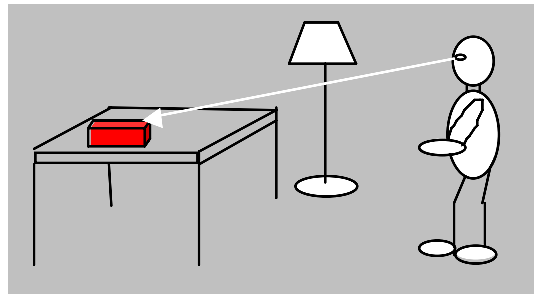

Figure 2.1 b   Simple emissions model.

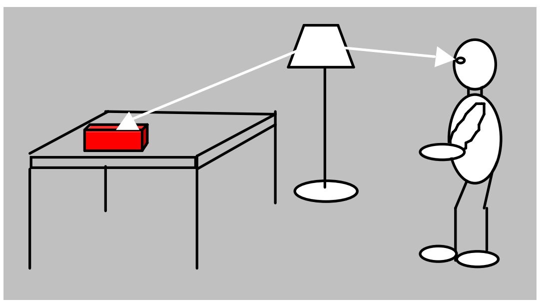

Figure 2.1 c   Dual emission model.

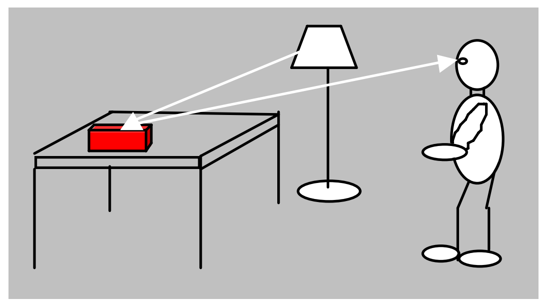

Figure 2.1 d   Scientific model: light is reflected by an opaque object.

Figure 2.1
Models of how light enables vision.

Reflected light carries an image. The third example: the concept is that light reflected from the object carries an image to the eye. The minority of fifth graders, who are able to accept that light is reflected from opaque objects, may maintain their hold on the ideas of active vision. The resulting model has a path going first from eye to object, then returning from the object to the eye with an image. It is an even smaller minority of fifth graders who can abandon their understanding of vision as active and accept the scientific notion that light reflected from opaque objects is received, rather than produced, by an eye (see Figure 2.1 d).

The experimental text was designed to address ideas about light and vision that typically present conceptual challenges for upper elementary students. An important design consideration of the present study was the understanding that, consistent with the landscape model of text processing, students are likely to activate their own conceptions to generate explanations of what they read – unfortunately, without recognizing that their explanation, based on a naïve conception, and the information in the text are incompatible (Kendeou & van den Broek, 2005). Thus, the graphics of the experimental text were designed to make challenging concepts about light and vision more understandable by explicating the prose and by revealing and confronting readers' competing conceptions. Outcome data from the present study provided quantitative and qualitative measures of participants' knowledge regarding these challenging concepts after reading the experimental text.

LINGUISTIC CHALLENGES

Just as upper elementary readers must move from everyday reasoning to scientific reasoning, they must also move from everyday language to the language of science. The language of science consists of specialized linguistic structures that can facilitate the cognitive work of producing and organizing scientific knowledge (Fang, 2005). Three linguistic characteristics of science text in general, and of the experimental text in particular, will be featured in the following discussion: technical vocabulary, nominalizations and content-dense sentence structures, and multiple, domain-specific text structures. It is the purpose of this discussion to show that these potentially helpful characteristics can also be challenging to interpret, especially to struggling readers. The language of science is essential to learning science; it makes it possible to think about the world in scientific ways (Veel, 1997). Therefore, analysis of participants' responses to the intervention reported here will focus, in part, on their use of linguistic features of the text.

Technical Vocabulary. Science text is characterized by the use of words with domain-specific, specialized meanings (Fang, 2006). These technical words are quite efficient in that a single word can reflect an accumulation of information and subsume a number of interconnected ideas (Martin, 1993; Schleppegrell, 2002). For example, in the experimental text on light and vision, the term 'reflect,' which figures prominently, subsumes a number of fundamental ideas (e.g., that light, emitted from a source, travels, strikes an object, and is re-emitted, or scattered). The challenges of technical terms are that they are also abstract and not easily defined. Even technical words for concrete objects, such as the structures of the eye in the experimental text, can seldom be defined simply. For example, to define the iris, one must include appearance (the colored part of the eye), and function (it contains muscles that expand and contract and so influence the size of the pupil). Technical words may be words that are used differently in science and in everyday life. The experimental text of the present study used ‘strike’ (i.e., light rays strike), which may be more familiar to upper elementary readers in the context of baseball.

Understanding multiple meanings for familiar words, or nuanced meanings of new words for abstract concepts or concrete objects, requires depth of word knowledge. For struggling readers, acquiring deep knowledge of technical words is, under the best of circumstances, a slow process requiring many exposures under a variety of conditions. But, deep knowledge of these words is important for learning science. Carlisle (2000) demonstrated a direct relationship between depth of knowledge of words that were central to a unit of science study and ability to solve problems using information from that unit of study. In view of this research, and as noted earlier, the intervention reported here provided support for key vocabulary. In the current study, knowledge of these words, gained in the course of reading the experimental text, was one of the dependent measures of readers’ learning.

Nominalization and Privileging of Content Words. Science text, as described by Fang (2004), is often constructed with a high proportion of content words (nouns, verbs, adjectives, and some adverbs) with nouns being especially privileged. In this way the writer can condense a great deal of information into a single sentence. While efficient, this abundance of content words results in lengthy sentences, dense with information, that place a heavy load on memory. The burden makes it difficult for the struggling reader to construct a coherent representation of science text. It is not uncommon for a content-rich clause or sentence to be synthesized into a single, more abstract noun or pronoun in a subsequent sentence. This construction, called nominalization, is illustrated in the example below from the experimental text. Note how the writer condenses the *italicized* description of a complex phenomenon into a single underlined pronoun or noun that becomes the subject of the next sentence.

> *In dim light the iris is narrow, which makes the pupil large, so that a lot of light can get into the eye. In bright light, the iris is wide, which makes the pupil small so that only a little light can get into the eye.* In this way, the iris allows the amount of light into the eye that we need to see.

Nominalization allows the writer to succinctly portray causal and temporal relationships and to set forth their ideas in a series of logical steps, each one building on the one that came before it (Halliday, 1993). In order to understand such arguments, however, the reader must correctly identify the nominalized phrases, which are the remote referents for often ambiguous nouns and pronouns (Fang, 2006). This is a task with which many naïve readers of science text have little experience and one that would be especially difficult for readers with the language processing difficulties typical of many struggling readers (Westby, 2002). In the present study, analysis of readers' oral responses to the intervention attended to the challenges of clearly establishing content nouns as referents for the more ambiguous pronouns typical of students' spoken language.

Domain-specific text structures. Authors of science texts arrange information and ideas into frameworks, or rhetorical structures particularly suited to the discourse of science. Examples of these structures include procedures, explanations, explorations, reports, and discussions (Veel, 1997). Each text structure has characteristic signals that, optimally, alert the reader to the organization and relations of the ideas (Carlisle, 2002). The reader who can use these signals as cues to identify the structures and understand their purposes can facilitate his or her own comprehension by organizing incoming information and setting expectations consistent with the discourse of the text (Meyer, 1984). In the following example (see Figure 2.2), the experimental text uses a theoretical explanation structure – a statement of theory (or claim) that cannot be derived from common sense reasoning, followed by supporting examples (or evidence) (Veel, 1997). The claim is that light must be reflected from an object to our eyes in order for us to see the object. The reader who is familiar with the explanation structure would realize that, from the perspective of the author, the claim is the big, important idea. What happens when light strikes the penny or different parts of the book constitutes supporting details, or evidence.

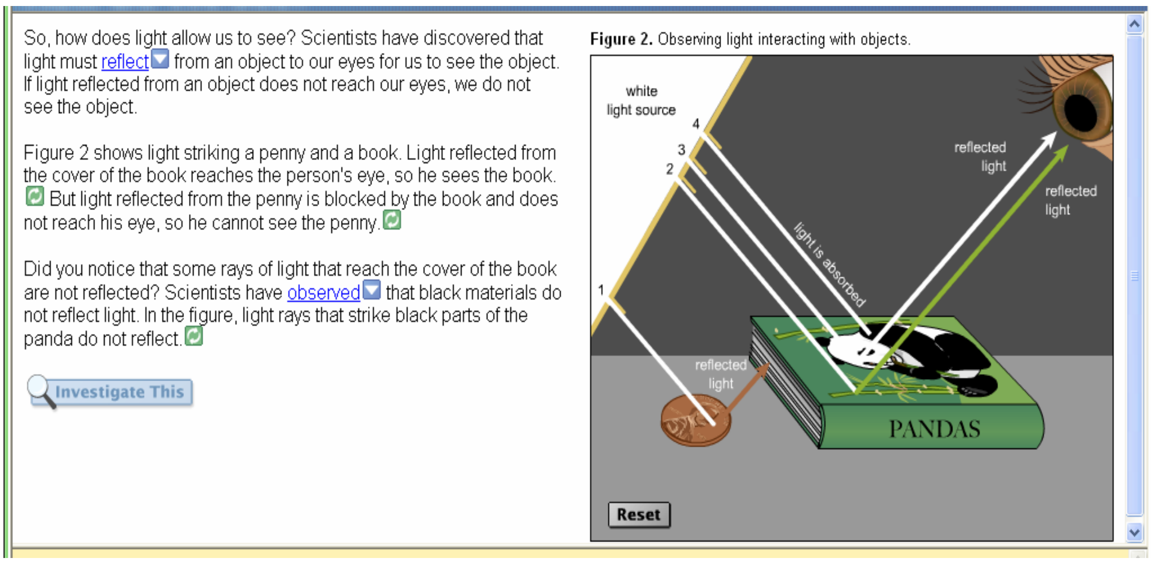

Figure 2.2
Claim-evidence text structure in the experimental text.

In the transition from reading mainly narratives to reading to learn from expository text, upper elementary readers find it difficult to use text structures to support their own comprehension (Carlisle, 2000). Readers cannot infer causes simply by following a temporal chain of events, as they have done with the narratives that often resemble their everyday experience. Nor can they rely on knowledge of a single rhetorical structure – many science texts are composed of multiple structures. Struggling readers have more difficulty than typically achieving readers in learning to use text structure as an aid to understanding and remembering information from informational texts (Englert & Thomas, 1987; Weisberg & Balajithy, 1989). In the present study, the analysis of readers' responses to the experimental text sought evidence of whether or not the readers' participation in the intervention facilitated their awareness and use of the rhetorical structures of the experimental text to support their comprehension.

Complementary graphics have the potential to support readers' interpretation of the challenging language of science text. Next, this discussion turns to the graphic representations to be found in science text, which have inherent challenges of their own.

Representational challenges

In spite of its abundant technical vocabulary and specialized sentence- and text-level structures, the language of science text is often inadequate to convey scientific ideas. Scientists must quantify and describe relationships among such variable phenomena as degree of temperature, speed and trajectory of travel, and shades of color (Lemke, 2002). They must also describe processes not usually available to perception, such as the reflection and absorption of light, and things not easily put into words, such as complex shapes. So, scientists employ visual-graphics such as maps, pictures, photographs, tables, charts, drawings, and diagrams to convey some aspects of scientific phenomena to complement the verbal messages. This discussion is limited to iconic graphics, which are the type of graphic found in the experimental text of the present study as well as in many other upper elementary science texts. These graphics will be described in terms of their appearance and information provided, as well as the challenges that they present to upper elementary students. Of particular interest are graphics that complement, and therefore must be integrated with, prose, if readers are to build coherent representations of scientific ideas. The relationships of prose to graphics will be considered. Of particular concern is the frequent failure of upper elementary students to integrate these graphics with their complementary prose.

Features of Graphics of Science Text. Hegarty, Carpenter, and Just (1991) provide a three-category taxonomy of scientific graphics based on the types of information provided and the manner in which the information is presented. The categories are: iconic diagrams, schematic diagrams, or graphs and charts. Iconic diagrams, usually pictures or line drawings, correspond closely in structure to the tangible objects or systems they depict (e.g., cross-section of a part of the body). Schematic diagrams show the functional, rather than structural, relationships of parts of an abstract entity (e.g., an organization, an electrical circuit). Graphs and charts display quantitative information which is interpreted with knowledge of the attributes of the graph or chart (e.g., positions, colors, shading). Like the iconic diagrams used by Hegarty and colleagues (1991), the graphics in the experimental text of the current study offer simplified, rather than detailed, views of objects to draw attention to features that are discussed in the prose. They show things that are not usually visible (e.g. the structures inside the eye). They also depict abstractions (e.g., light interacting with the structures of the eye). And, they depict dynamic elements (e.g., arrows indicate that the light enters the eye and travels to the brain).

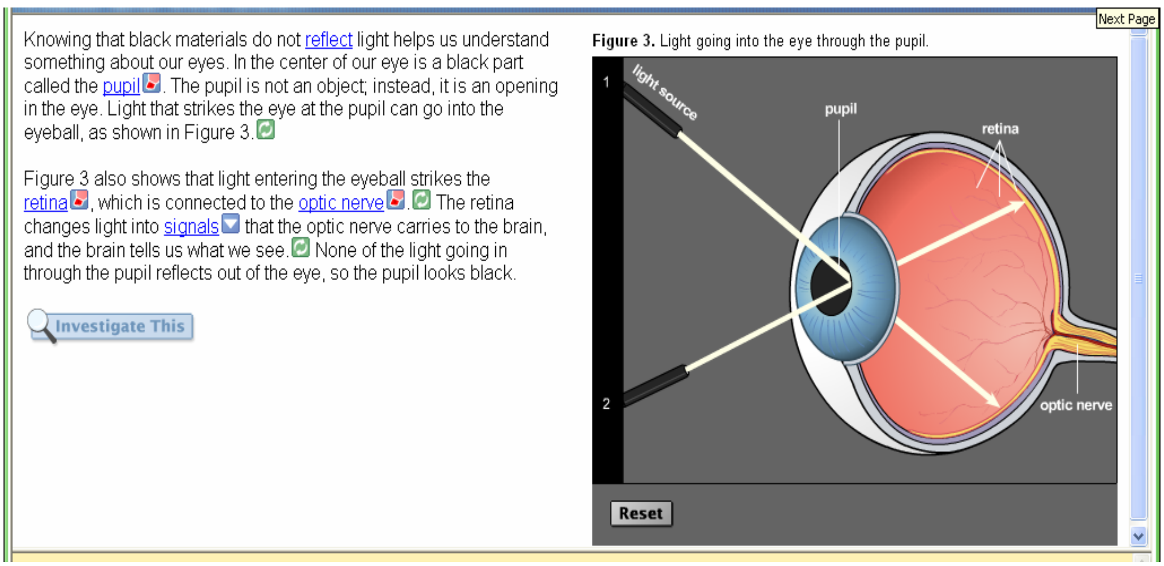

Figure 2.3
An iconic diagram from the experimental text.

Challenges to Interpreting the Graphics of Science Text. To understand the challenges these graphics present, it is helpful to think in term of ‘depicting codes’ and ‘directing codes’ (Weidenmann, 1994). Depicting codes construct a real-world surface structure, that is, situations and objects in their characteristic proportions (Weidenmann, 1994). Depicting codes are usually easily interpreted by those who are familiar with the real-world referent for the situation or object. Directing codes create a visual argument, sometimes by means of deviations from real-world appearance (Weidenmann, 1994).

These are devices (e.g., distinct colors, labels, arrows, simplified appearance as in Figure 2.3) that signal what should be salient about a figure. They direct the reader to engage in the cognitive activities (e.g., comparing structures of the eye, mentally simulating motion of light, or imagining the consequences of light interacting with structures of the eye in Figure 2.3) necessary to build an accurate mental model with the figure. For insights into the task of interpreting the complexities and conventions of scientific graphics, this discussion turns to the work of diSessa, who has studied the metarepresentational competence (MRC) of school-aged children. MRC is defined as the ability to design, modify, understand, explain, evaluate, and learn new representations (diSessa, 2004).

Two related factors that affect how upper elementary readers approach graphics in science text are their status as novices to the domain of science and their extensive experience in the domain of the narrative. diSessa (2004) suggests that students interpret graphics in a manner that is consistent with the purposes for which they have historically employed graphics. Upper elementary students have been operating in the real world and reading mostly narratives. The competence they have developed in interpreting visual images is "at least initially, better adapted to… telling comprehensible stories than to scientific ends" (diSessa, 2004, p. 327). DiSessa (2004) provides the following examples which juxtapose the narrative-based metarepresentational competence of students with the metarepresentational demands of science text: In narrative illustrations and in the real world, perceptual features are often important, so students are attuned to color, size, shape, and patterns or changes in these as salient to the message of the text. In science, these may be surface features of no great import, except as they systematically represent features (e.g., rate or trajectory of motion) central to a concept. Real world and narrative representations work best if they are realistic, so students may evaluate representations on this basis. By contrast, scientific representations sacrifice realistic depiction of an object in favor of an image that is made more abstract to amplify an important relationship. Numbers are important in the real world and in science, so novice readers of scientific texts attend to quantitative representations. For scientists, though, qualitative representations can be more useful than numbers. Some patterns (e.g., degrees of temperature) are easier to see as colors rather than as numbers.

If readers are to align their metarepresentational skills with scientific purposes, then they must become familiar with the practices of science (diSessa, 2004). The experimental text of the present study used animated and interactive graphics to model scientific methods of inquiry, reasoning, and communication. The use of animated and interactive graphics will be discussed in the final section of this literature review on the use of technological tools to support learning from text. First, though, it is important to attend to another important aspect of scientific graphics – the relationship of graphics to prose.

Relationship of Graphics to Prose. Novice readers of science text have at their fingertips a helpful, but often under-utilized resource for interpreting graphic information – accompanying prose. In science text, prose and graphics can often be complementary (Lemke, 2000). That is, the graphics depict phenomena that cannot efficiently be put into words, and the accompanying verbal messages provide explanations of relationships that are not readily apparent in a visual image. Readers learn scientific ideas in the integration of these multiple representations. “What it means to be able to use a scientific concept… is to be able to fluently juggle with its verbal… and visual-graphical aspects, applying whichever is appropriate in the moment… it is only in the integration of these various aspects that the whole concept exists” (Lemke, 2000, p. 248).

Hegarty and colleagues (1991) provide a taxonomy that outlines possible relationships between prose and iconic graphics; they may be complementary, redundant, or guides for interpretation. Complementary prose and graphics “provide different types of information about the same referent” (p. 648). In Figure 2.3, the graphic carries information about the spatial relationships of structures of the eye; the prose describes their functional relationships. Redundant prose and graphics provide the same information, to assist the reader who may not efficiently process information from only prose or graphic. Figure 2.2 was designed with the knowledge that upper elementary students often have a naïve conception about how light enables vision. Anticipating that information regarding the scientific notion of the behavior of light would meet resistance from these naïve conceptions, the information was presented in both prose and graphic forms. Prose that guides the interpretation of graphics does so with explicit references to features of the graphic. It seems that this relationship is likely reciprocal. That is, graphics may also guide the processing of prose. In Figure 2.3 the prose description of how light interacts with structures of the eye refers to parts of the eye (e.g., pupil, iris, optic nerve) that are also labeled in the adjacent figure. Arrows in the figure orient the reader to the origin, trajectory, and points of interaction along the path of light.

In spite of the potential benefits of linking prose and graphics, there is evidence that many novice readers fail to integrate graphics and prose and thus fail to learn optimally from science text. Most of this evidence has been developed in research with college-aged participants and so is probably not applicable to upper elementary students. Two programs of research speak specifically to the experiences of upper elementary students reading science text; only one of these included struggling readers. Moore and Scevak (1997) used think-aloud protocols to study the ways in which 5th, 7th, and 9th graders, average and above-average readers, processed the information in science texts which included a tree diagram. The researchers found developmental differences in the degree to which participants integrated information from prose and graphics. While 48% of 9th graders reported how information in the graphic facilitated their understanding of the prose, 5th and 7th graders rarely did so.

Phase one of the work of Dalton and Palincsar (2004), which was introduced in Chapter 1, also used a think-aloud methodology to study the reading processes of 5th graders, struggling and typically-achieving readers, who read a text rich with iconic graphics. Dalton and Palincsar also found that 5th graders rarely integrated information from graphics and prose. The readers who made the greatest gains in conceptual knowledge after reading the experimental text were those whose protocols showed the greatest evidence of prose-graphic integration. Struggling readers were less likely than typically achieving readers to integrate graphics and prose.

It was the purpose of the intervention reported here to study the effects and affordances of two experimental features designed to facilitate the integration of graphics and prose. Those features will be described in detail in the methods section to follow.

Using Technological Tools to Support Learning from Text

The preceding discussion of the challenges that struggling readers face in comprehending text generally, and in meeting the linguistic, graphic, and conceptual challenges specific to science text, suggests that these readers are likely to face cognitive overload when trying to integrate the graphics and prose of science text. That is, their working memories may become overwhelmed by the demands of simultaneously processing adjacent verbal and visual information from a "difficult-to-learn" context (Paas, Renkl, & Sweller, 2003). Computer technologies can serve as "intellectual partners" (Salomon in Pea, 1993, p. 75) offering guidance and tools that enable readers to learn in difficult-to-learn contexts. Such cognitive tools can be embedded in electronic text, or textual material presented on a computer text to enable readers make the most efficient and effective use of their own cognitive resources. For example, "virtual realities," or visual models that can be manipulated so that they behave like real-world phenomena, when embedded in text, offer rich opportunities to reason about scientific phenomena.

Anderson-Inman and Horney (2007) have developed a typology of the ways in which electronic text may be transformed to support reading and learning; several enhancements to electronic text are relevant to the present study. *Translational resources*, which change print into more accessible or understandable forms, in the present study, included text-to-speech and definitions. *Illustrative resources*, which provide visual representations of ideas in the text, included the animate-able iconic graphics of the text. The Manipulable Graphics and the Highlight & Animate Feature of the present study may be considered *instructional resources*, since they provide prompts and opportunities to investigate and interpret the ideas of the graphic-rich text in particular ways. The review of the research that follows addresses each of these resources with particular attention to instructional resources that guide readers in strategic activities known to contribute to constructing coherent representations of text. It is the purpose of this study of Manipulable Graphics and a Highlight & Animate Feature to contribute to our understanding of how instructional resources may be designed to support struggling readers to learn with graphic-rich science text by interpreting and integrating prose and graphics.

TRANSLATIONAL RESOURCES

Text-to-speech: support for word recognition. Text-to-speech (TTS) is synthetic, computer-produced speech that enables readers with poor word recognition skills to access text with unfamiliar, difficult-to-pronounce words. Typically, in response to commands from the reader the computer reads aloud while simultaneously highlighting the words, so that the reader can follow along. The purpose of using TTS with struggling readers is to improve comprehension in two ways: 1) enhance the salience of information through bimodal – visual and auditory – presentation (Okolo, 2005) and 2) decrease cognitive demands by offloading the task of word recognition to the computer, so readers can devote their cognitive resources to comprehension (George, Schaff, & Jeffs, 2005). Reviews of research show that the use of TTS can improve comprehension of text, especially for upper elementary, struggling readers who are reading age-appropriate (challenging) text (Balajthy, 2005; Raskind & Higgins, 1999; Strangman & Dalton, 2005). In view of the cited research, the digital environment of the present study – with struggling, upper elementary readers and challenging text – included TTS support.

Vocabulary hyperlinks: support for understanding words. Supported electronic texts offer opportunities to develop knowledge of important but unfamiliar words through hypertext links to glossary, simpler synonyms, examples of words used in sentences, and illustrations or graphics enhanced with narration. Several studies have demonstrated the effectiveness of these resources in improving vocabulary knowledge, particularly for readers with limited vocabulary knowledge due to learning difficulties or sensory impairments, or second language learners (Blachowicz, Beyersdorfer, & Fisher, 2006; Bus, de Jong & Verhallen, 2006; Higgins, Boone & Lovitt, 1996; Horney & Anderson-Inman, 1994; MacArthur, Ferretti, Okolo & Cavalier, 2001). Given the importance of vocabulary knowledge to reading comprehension in general, and to learning from science text in particular – as documented earlier in this literature review – the digital environment built for this intervention study incorporated several types of vocabulary supports.

ILLUSTRATIVE RESOURCES

Animation: support for interpreting graphics. Research supports the use of animated graphics to meet the requirements of certain tasks or to support learners with certain characteristics. With respect to tasks: in a review of the literature, Park and Hopkins (1993) found animated visual displays were often effective when instruction was required to guide attention, represent concepts through action, depict structural and functional relations among components, support formation of a mental image of systems that are not directly observable (e.g., circulation), or create a visual analogy to make abstract concepts (e.g., velocity) more concrete and observable.

Regarding learner characteristics: Hegarty and colleagues (Hegarty, Quilici, Narayanan, Holmquist, & Moreno, 1999; Mayer, Hegarty, Mayer, & Campbell, 2005), using experimental tasks that were consistent with the criteria of Park and Hopkins (1993), found no advantage of animation over static graphics for undergraduates learning how unfamiliar, complex mechanical and biological systems work. The investigators hypothesized that students learned how the systems worked by first building static mental models primarily from illustrations but also from accompanying text. Then, inferring the causal principles of operation, the students mentally animated, or simulated, the system. Providing these undergraduates with animation did not improve their learning; rather, the investigators suggested that engaging in mental animation was an important step in participants' learning. However, the investigators proposed that for readers who may not be able to construct mental animation from static representations, for example, readers who are young and inexperienced in the use of domain-specific graphic representations, animated graphics might be superior to static graphics in improving understanding.

Very little research on learning from animated graphics has been conducted with school-aged children (Anglin, Vaez, & Cunningham, 2004). In one of the only programs of research on animated graphics with upper elementary readers, Rieber (1989, 1990a, 1991a, 1991b) presented 4th, 5th, and 6th graders with static and animated diagrams in a text based on Newton's laws of motion. Students experienced "subtle" benefits from text with animated graphics. It is possible that the benefits were only subtle because Rieber directed participants to attend to the graphics by removing print to a separate screen and/or providing narration. Thus, participants would not have had adjacent prose and graphics to integrate, a design contrary to the temporal contiguity principle for the design of graphic-rich text (Mayer, 2002).

In light of the research cited above, the digital environment of this study incorporated animated graphic for several reasons. The instructional demands of the experimental text of the present study were much like those that Park and Hopkins found conducive to the use of animated graphics (e.g., key concepts not available to perception). The participants were much like those for whom Hegarty recommended the use of animated graphics (e.g., novices, lacking the scientific metarepresentational competence to construct static models and then mentally animate the static figures). And, unlike the texts used by Rieber, the experimental text of this study offered a potentially more powerful combination of adjacent and complementary prose and graphics. It should be noted that the question of whether static or animated graphics would better facilitate learning with the text of the present study had already been addressed in the Intervention Study of the Program of Research on Reading Comprehension. In that study, struggling readers and typically reading participants, who were provided with animated graphics, learned more than participants who read the same text (*How Do We See)* with static graphics (Dalton & Palincsar, 2004). The research question in the present study concerned how readers made use of supports that employed animated and interactive graphics.

INSTRUCTIONAL RESOURCES

Research on two types of instructional resources is described below: 1) interactive graphics for reasoning about phenomena, and 2) instruction and prompts to engage in cognitive and metacognitive strategies. These two types of instructional resources align in purpose with the Manipulable Graphics and the Highlight & Animate Feature of the present study. Interactive graphics are typically presented in environments with minimal prose, and strategic prompts, usually focus exclusively on the message presented in prose. In contrast, the current study provided interactive graphics (Manipulable Graphics) in the context of considerable information in prose that was needed to fully exploit the affordances of the graphic. And, the strategic prompts (Highlight & Animate Feature) were specifically designed to guide interpretation of the prose in light of an adjacent graphic. I could find no examples of research that has developed electronic text to support reasoning by interpreting and integrating the messages from both graphics and prose, as the current study did. Virtually all of the research to be sited involves learning in the domain of science. Accordingly, this research will provide helpful perspectives from which to evaluate the current study.

Interactive graphics. In a review of research on learning with computers, Kozma (1991) described properties of interactive graphics that supported novices engaged in scientific inquiry to build more expert-like models. These graphics can represent not only the tangible objects usually included in novices' models, but also the intangible entities (e.g., dynamic properties of light) usually absent from novices' models. Symbols such as arrows can be endowed with properties that cause them to behave like the intangible entities they represent (e.g., an arrow travels from a source to an object and then to the eye). When learners manipulate the symbols for real objects and abstract entities, they may discover, in the consequences of their actions, the laws that govern the phenomena and the ways in which these laws contrast with their own conceptions.

Rieber (1990b) introduced learners to potentially conflicting ideas in order to provide structured opportunities to resolve the conflicts through strategies such as hypothesis testing via interaction with an animate-able figure. In the present study, interactive graphics, called 'Manipulable Graphics,' were used for several purposes: to direct readers to study important features of the graphic, to enable readers to discover scientific principles as they investigated multiple variations on the behavior of phenomena, and to prompt readers' to confront their own naïve conceptions about important ideas of the text. Analyses of participants' responses to the experimental conditions asked how the Manipulable Graphics mediated readers' learning.

Studies using interactive graphics to support novices to learn complex ideas from informational text are often be found in the science literature. One example of an environment in which learners used interactive graphics was Chemation, a tool for building models of molecules, modifying their properties, manipulating them in a variety of ways, and inspecting the effects (Quintana, Chang, & Krajcik, 2007). Middle school students who used Chemation were better able to explain some chemistry concepts and more likely to use chemical names and formulas in their explanations. The digital environment of the present study adopted some of the applications of technology from the perspective of science research to prompt actions that were constructive, generative, and metacognitive.

Cognitive and metacognitive strategy prompts. Just as science researchers are developing technologies to guide apprentice scientists to adopt the thinking and practices that scientists use to construct knowledge, reading researchers are harnessing technology to prompt developing readers to engage in the cognitive activities that expert readers use to build knowledge. Recent, promising examples of instructional resources include digital environments (supported electronic texts) that teach comprehension strategies. These digital environments offer expert models, guided practice, specific and immediate feedback, and gradually faded support for readers to build knowledge from text. They are often fashioned after well-established reading comprehension interventions, which, ideally, may prove even more efficacious for even more readers when offered via technology. Indeed, investigators have reported that greatest benefit of these environments has been realized by the readers most in need of support (Anderson-Inman & Horney, 2007). Several relevant examples of this work will be reviewed briefly here as the issues they raise can inform decisions about implications of the present study for *future* design and research on instructional resources for supported electronic texts. Note that most of the following investigations were conducted in approximately the same time period as the present study, and the results were just recently published. So, they did not inform the design of the present study. Each of the following investigations was conducted, at least in part, with readers of similar age and levels of reading achievement as the participants in the present study.

Caccamise, Franzke, Eckhoff, Kintsch, & Kintsch (2007) sought to improve comprehension of expository text through summarizing. Their program, Summary Street, analyzed readers' summaries using latent semantic analysis (LSA), then provided graphic feedback alerting the reader to redundancy, irrelevance, excessive detail, or plagiarism. Participants who used Summary Street for 5-6 passages consistently out-performed a control group in the quality of the summaries they produced. One intriguing aspect of Summary Street was its potential to supplement teachers' instruction with multiple practice opportunities and immediate, individualized feedback to any number of students virtually simultaneously – in the time a teacher could respond to one student. The trade-offs to be made between the number of students who can get simultaneous feedback and the quality of feedback that can be supplied through computerized linguistic analyses is a topic well worth considering in the design of future research.

Intelligent tutoring of the structure strategy (ITSS) (Meyer & Wijekumar, 2007; Wijekumar, 2007; Wijekumar & Meyer, 2005) is a web-based program that uses an animated pedagogical agent to teach readers how to identify expository text structures and then use those structures to organize comprehension and recall of information. ITSS moves readers through a series of steps, providing practice with gradually less explicit prompting, in components of the structure strategy such as writing the main idea. After using ITSS, participants demonstrated improvements on a standardized test of reading comprehension. The ITSS system seemed elegant in its carefully sculpted steps to mastery of a skill. One aspect of this investigation that is applicable to supported electronic text in general is the balance to be achieved between making a system that is widely applicable – e.g., to texts in a variety of domains – and teaching skills that are sufficiently domain-specific to support comprehension of texts within a particular domain.

Another program of research, the Universal Learning Environment (ULE) (Dalton & Proctor, 2007) allows readers to choose the amount of assistance they need to predict, question, clarify, summarize, or visualize when prompted to do so. ULE is based on principles of universal designs for learning (UDL), a philosophy applicable to enabling learning with technology. As stated by the founders of the Center for Applied Special Technologies (CAST), the proponents of universal design believe that “barriers to learning are not, in fact, inherent in the capabilities of learners but instead arise in learners’ interactions with inflexible educational materials and methods” (Rose & Meyer, 2002). Technology provides opportunities to design materials and methods accessible and adjustable to all learners. Like Dalton and Proctor, Johnson-Glenberg (Johnson-Glenberg, 2007) used supported electronic text to teach the use of strategies, many of which were based on reciprocal teaching intervention. Strategies included visualization, rereading, question answering, question generation, summarization, and comprehension monitoring in a system called the 3D Reader.

Current technologies have progressed far beyond the strategic tools of a decade ago – hyperlinks to explanations and supplemental background information, main-idea highlighting, summaries or outlines, note-taking opportunities, or comprehension questions with corrective feedback – which proved effective, under certain conditions, in facilitating comprehension for readers who had difficulty learning from text (Anderson-Inman & Horney, 1998; Strangman & Dalton, 2005). Subsequently, researchers have aligned new technologies with research on reading comprehension instruction to create more tailored, potentially powerful learning environments that have proven particularly effective for struggling readers.

However, advances in technology which enable the development of instructional resources for electronic texts is well ahead of the research base on the most effective design and application of those resources to support struggling readers to learn from text. Hegarty (2004) states, for example, that our technological capacity to produce multimedia is currently well-in-advance of research to establish how characteristics of the reader, cognitive demands of the content, and the multimedia features of text should be aligned to produce an optimum learning environment for a particular reader. In a review of the state of the art in research on supported electronic text, Anderson-Inman (2007) sets an ambitious agenda for future research. Questions to be investigated included:

- What are effective delivery modes for different resources that support electronic text?
- What are powerful combinations of these resources?
- What are appropriate levels of student control of these resources?
- What are the interactions between texts, resources, and tasks?

I will return to these questions when discussing the conclusions that may be drawn from the present study of two specific resources designed to support struggling readers to construct and integrate meaning from both prose and graphics of graphic-rich science text.

CHAPTER THREE: METHODS

This is a quasi-experimental study of struggling readers interacting with a digitized science text, which was enhanced with animated and interactive graphics. The purpose of the study was to examine the effects and affordances of two experimental features of the text – a Highlight & Animate Feature and Manipulable Graphics. Each feature was designed to offer the reader unique opportunities to interpret and integrate graphics and prose. In a between-groups design, fifth-grade struggling readers were randomly assigned to one of two conditions. Those in the Highlight & Animate Condition read the text, *How Do We See*, using the Highlight & Animate Feature. Participants in the Manipulable Graphics Condition read the same text using the Manipulable Graphics. The research questions concern the effects of these features.

RESEARCH QUESTIONS

1) What were the effects of the Highlight & Animate Feature or the Manipulable Graphics on participants' knowledge of the topic of the experimental text? That is, after reading the text:
    a. How much knowledge did participants gain?
    b. How well did participants articulate understandings of important ideas?

2) How did the Highlight & Animate Feature or the Manipulable Graphics mediate participants' interaction with the experimental text? That is:
    a. How did participants use the affordances of the Highlight & Animate Condition or the Manipulable Graphics Condition?
    b. How did participants meet the conceptual, linguistic, and graphic demands of the experimental text in the Highlight & Animate Condition or in the Manipulable Graphics Condition?
    c. How did participants within each condition vary in their use of the affordances of the Highlight & Animate Feature or the Manipulable

Graphics and in their meeting the conceptual, linguistic, and graphic demands of the text?

Mixed methods of analysis were used to answer these questions. Objective assessments of text-specific conceptual knowledge and vocabulary were administered to participants before and after they interacted with the digital text. Quantitative methods were used to determine how much participants gained from pre- to post-test on the objective assessments, if the gain was significant, and if there were differences in knowledge gained by condition. As they interacted with the text, readers made spontaneous comments and participated in interviews about what they were learning; these statements were recorded and transcribed. Qualitative methods were applied to these data to describe participants' statements of their understanding about light and vision and determine how well their statements aligned with those of experts, as presented in *How Do We See*. Each move participants made in the digital environment was also recorded electronically. Participants' statements and nonverbal moves were also analyzed qualitatively to demonstrate how interactions with text varied with respect to the affordances of the two conditions, the demands of the text, and characteristics of individual participants.

Participants

Participants were twenty fifth-grade students, 8 boys and 12 girls, two of whom were designated by school personnel as learning disabled. The primary criterion for selection of participants for this study was status as a struggling reader. All participants scored one or more standard deviations below the mean for grade 5 on a standardized assessment of reading comprehension, the *Gates MacGinitie Reading Test* (MacGinitie, 1999). Additional standardized measures, subtests from the *Woodcock-Johnson III Tests of Achievement* and *Tests of Cognitive Skills* (Woodcock, Mc Grew & Mather, 2001), were used to quantify some of the linguistic and cognitive resources participants brought to the tasks of the study. Performances on these standardized measures are presented in Table 3.1 and the following narrative.

Table 3.1
Standardized measures of participants' cognitive and linguistic resources

Measure	Sample Mean (SD)	Range
Gates-MacGinitie Comprehension of Paragraphs	15.9 (9.3)[2]	1-32
Woodcock-Johnson III: Letter-Word Identification	87.8 (8.5)[3]	71-103
Woodcock-Johnson III: Picture Vocabulary Subtest	92.5 (9.4)	71-113
Woodcock-Johnson III: Spatial Relations Subtest	107.1 (13.9)	83-137

READING ACHIEVEMENT

On the comprehension of paragraphs portion of the *Gates-MacGinitie Test of Reading* participants read passages silently, then read and answered multiple choice questions about the passages. The distribution of scores on this test (see Table 3.1) suggested that participants had sufficient difficulty understanding what they read to be characterized as struggling readers. Twenty-five percent of the participants scored 1-1.5 standard deviations below the mean for grade; 55%, 1.5-2 standard deviations below; 20%, 2 or more standard deviations below.

On the *Letter-Word Identification Subtest* of the *Woodcock-Johnson Tests of Achievement* participants read aloud single words without contextual support. On average, participants' scores fell one standard deviation below the mean for grade 5 on this measure (see Table 3.1). Consistent with their low reading comprehension scores, 40% of participants achieved word identification scores that were one standard deviation or more below the mean. However, 60% of participants, including most of those with the lowest *Gates MacGinitie* scores, achieved word identification scores that were within one standard deviation of the mean, or within the normal range. This suggests that some participants may have had relatively more difficulty with reading comprehension than might be expected on the basis of their word recognition skills alone.

[2] Scores are reported as normal curve equivalents: mean = 50; standard deviation = 21.
[3] Woodcock-Johnson subtest scores are deviation quotients: mean = 100; standard deviation = 15.

LINGUISTIC AND COGNITIVE SKILLS

The *Woodcock-Johnson Picture Vocabulary* subtest measured general expressive vocabulary, a necessary prerequisite for word recognition and text comprehension. There was considerable variation – from one standard deviation above the mean to two standard deviations below the mean – in participants' scores on this assessment (see Table 3.1). Most (75%) of participants had expressive vocabulary skills that were within one standard deviation of the mean for grade 5. Expressive vocabulary scores that fell below expectations for grade 5 indicated that some participants may have had language difficulties, which would be consistent with research that shows a high co-occurrence of oral and written language difficulties (see Catts, Fey, & Tomblin, 2002; Catts & Kamhi 2005).

The *Spatial Relations* subtest of the *Woodcock-Johnson Cognitive Assessments* required that participants match complex shapes in order to gauge their ability to interpret figures. The choice of this subtest was based on a concern that participants had to interpret figures in the experimental text. All participants achieved scores that were within the normal range, or higher (see Table 3.1). It should be noted that the directions for administration of this test impose no time limits for completion, nor does the scoring take into account the time it takes an individual to take the test. Yet, my observation was that fifth graders varied widely in the amount of time they took to complete this test. It is my impression that time limits may have produced less inflated scores and provided more insight into participants' resources for interpretation of graphics.

KNOWLEDGE ABOUT LIGHT AND VISION

Experimental measures sampled participants' entering conceptual knowledge about how light enables us to see and vocabulary knowledge specific to the text, *How Do We See* Table 3.2 and the following narrative characterize participants' entering knowledge.

Table 3.2
Experimental measures of participants' entering conceptual knowledge and vocabulary

Pretest	Mean Number of Items Correct	Range
Conceptual Knowledge (9-item)	3.4 (1.43)[4]	0-6
Text-specific Vocabulary (10-item)	5.7 (1.6)	1-8

The *Conceptual Knowledge Pre-Test* (see Appendix B) was an experimenter-designed, multiple choice measure of understanding of concepts specific to the topic of the experimental text. On average, participants entered the study with a modest amount of knowledge about light and vision: 3.4 items correct out of nine (see Table 3.2). Participants with the lowest scores in reading comprehension had the lowest – and the highest – pre-test scores on this measure of knowledge about light and vision. Thus, reading comprehension did not predict prior knowledge, a finding consistent with earlier research (see Palincsar, Magnusson, Collins, & Cutter, 2001). The construction of this instrument will be addressed later in this chapter.

The *Text-Specific Vocabulary Test* (see Appendix C) was a 10-item, experimenter-designed, multiple choice measure of vocabulary specific to the experimental text. Participants entered knowing, on average, about half of the target words (see Table 3.2). No items were familiar to all participants; some were familiar to most: evidence, reflect, absorb. Again, the design of this instrument will be addressed later in this chapter.

SETTING

The 14 white and 6 African American participants were native speakers of English who came from four elementary schools in three Southeast Michigan school districts. The considerable variation in student demographics across districts is depicted in Table 3.3. All participants consented verbally to engage in the tasks of the study and parents provided written consent.

[4] Score is number of items answered correctly.

Table 3.3
Characteristics of participants' school districts

District	N	Economically disadvantaged	Disabled	White	African American
A	5	40%	11%	93%	3%
B	10	17%	16%	83%	7%
C	5	65%	20%	41%	56%

Materials

THE TEXT

The experimental text, *"How Do We See"* was an 800-word text on the topic of light and vision[5]. It had a Flesch-Kincaid readability level of 5.2. In earlier work in the *Reading to Learn* program of research described in Chapter 1, fifth graders found *How Do We See* to be challenging. (It was important that the experimental text be challenging so that the participants would need a supported electronic text.) The big idea of the text – that we need light to see because we see only when light is reflected from an object to our eyes – and the difficulty that this idea often presents to fifth graders were described in Chapter 2. In the digitized environment, the text was presented on eight pages, or screens. On seven of the eight pages, a graphic accompanied the prose. Six of the seven pages with graphics offered scaffolds for interpreting and integrating prose and graphic messages. These scaffolds distinguished the experimental conditions.

In the Highlight & Animate Condition, scaffolding was provided by the Highlight & Animate Feature. In the Manipulable Graphics Condition, scaffolding was supplied by the Manipulable Graphics. The Highlight & Animate Feature and the Manipulable Graphics are described below. These features created different perspectives on the prose and graphics used to portray the same concepts in each condition. They provided opportunities for participants to interact with the important ideas of the text in somewhat different ways, by condition. The ways in which the presentation of important ideas via

[5] The supported electronic text, *How Do We See*, is the same text that was developed for the Intervention Study in the *Reading to Learn* research introduced in Chapter One.

the graphic varied across conditions is described and illustrated in Appendix A. Every page of the text in each condition offered vocabulary support and text-to-speech (TTS) to facilitate access to the prose, which was identical across conditions.

THE HIGHLIGHT & ANIMATE FEATURE

In the Highlight and Animate Condition, small, green Highlight & Animate symbols (1-3 per page) appeared at the end of certain sentences to alert readers to important ideas that were further explicated by the graphic. Readers were instructed to activate each Highlight & Animate symbol as they came to it in the course of their reading. Activating the symbol precipitated two simultaneous events: a sentence that expressed an important idea was highlighted in yellow, where it appeared in the prose, and its corresponding representation in the graphic was animated (contrast Figures 3.1 and 3.2). (Note that figures will frequently be drawn from page 2 of *How Do We See* so that the reader can consider new information reported about the experimental study without also considering new information presented in the experimental text.)

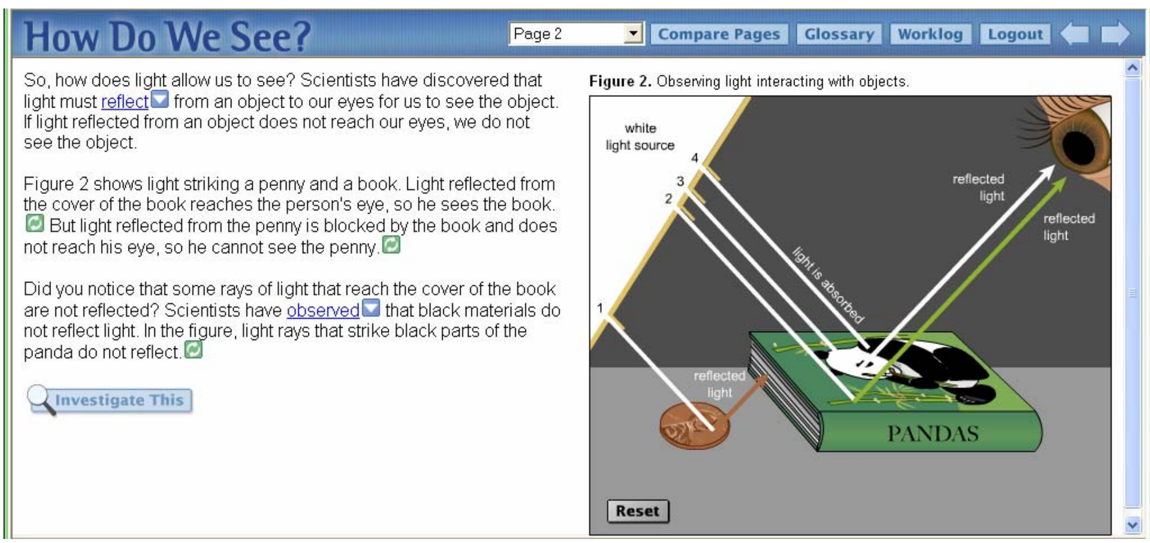

Figure 3.1
The Highlight & Animate Feature before the reader activated it

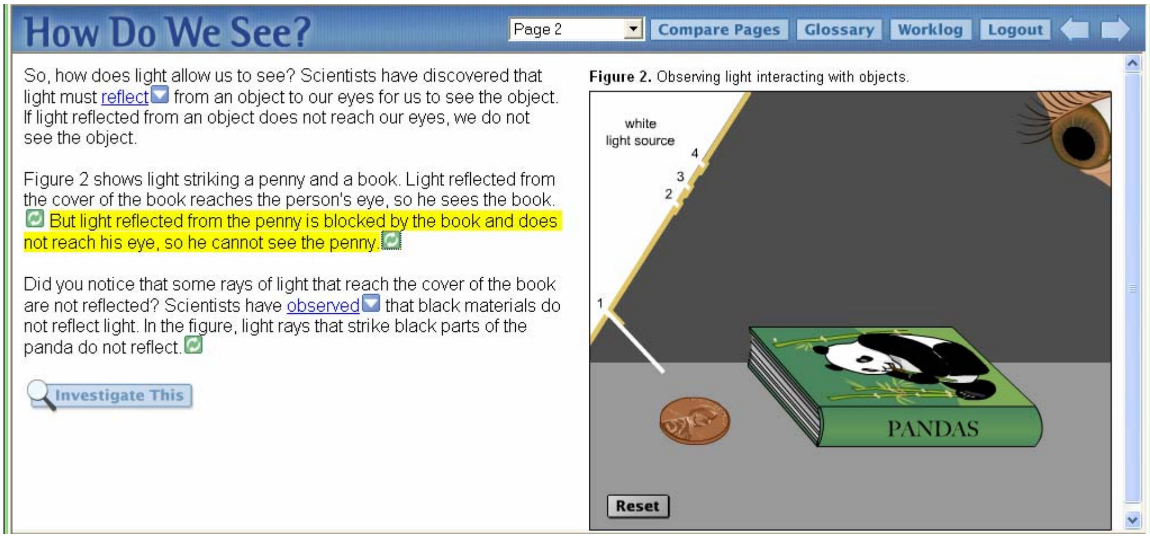

Figure 3.2
The Highlight & Animate Feature as the reader activated it

An important idea is highlighted and the figure has been animated to demonstrate the highlighted idea – light travels to the penny, but is blocked by the book, so it does not reach the person's eye.

The Highlight & Animate Feature offered certain affordances, or opportunities, of which readers might take advantage. The affordances were designed to facilitate readers' interpretation and integration of prose and graphics. While described here in sequence, these opportunities were actually presented simultaneously. The Highlight & Animate Feature directed readers to:

- Attend to the specific structures, functions, and phenomena that were important for interpreting the graphic by making those aspects of the graphic explicit via animation. The animation, a 'directing code' (see Weidenmann, 1994), invited readers to engage in particular cognitive activities (e.g., compare the outcomes of two events) likely to facilitate correct interpretation of the graphic.

- Identify and review the most important ideas in very dense prose by highlighting those ideas. This highlighting also served as a 'directing code,' inviting readers to consider, compare, and connect highlighted ideas and use those ideas to gain a foothold in difficult-to-read prose.

- Refer to the graphic at the appropriate point in the reading and tack between prose and graphic by simultaneously highlighting the prose and animating a graphic. Concurrent highlighting and animating invited readers to see ideas in prose and graphics as aligned and integrate those ideas, using one to expand, explain, clarify, or confirm the other.

THE MANIPULABLE GRAPHICS

In the Manipulable Graphics Condition, the Manipulable Graphics were designed to engage readers in an investigation of the ideas offered in the prose as well as the readers' own ideas. The Manipulable Graphics offered variations and contrasts designed to complement the partial understandings and confront the naïve conceptions readers were expected to bring to the text. Opportunities to manipulate the graphic were provided on the same page that described the specific example of phenomena depicted in the graphic and the general scientific principle to be drawn from the example (see Figures 3.3 and 3.4). 'Directions to investigate' told readers what features of the graphic could be changed and how to change them. The reader could make these changes multiple times.

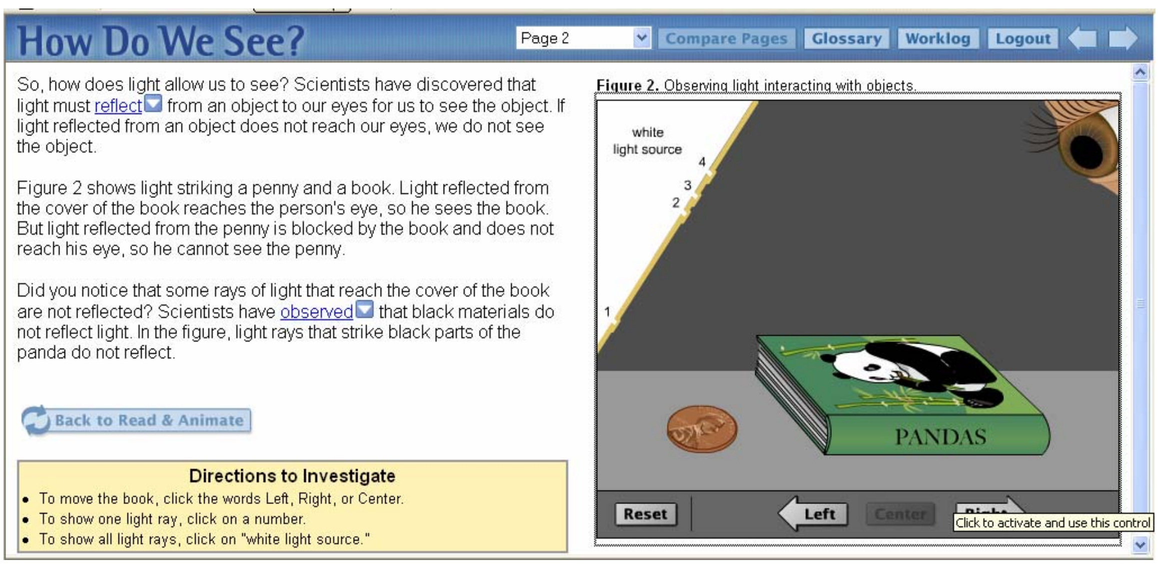

Figure 3.3
The Manipulable Graphic before the reader manipulated it

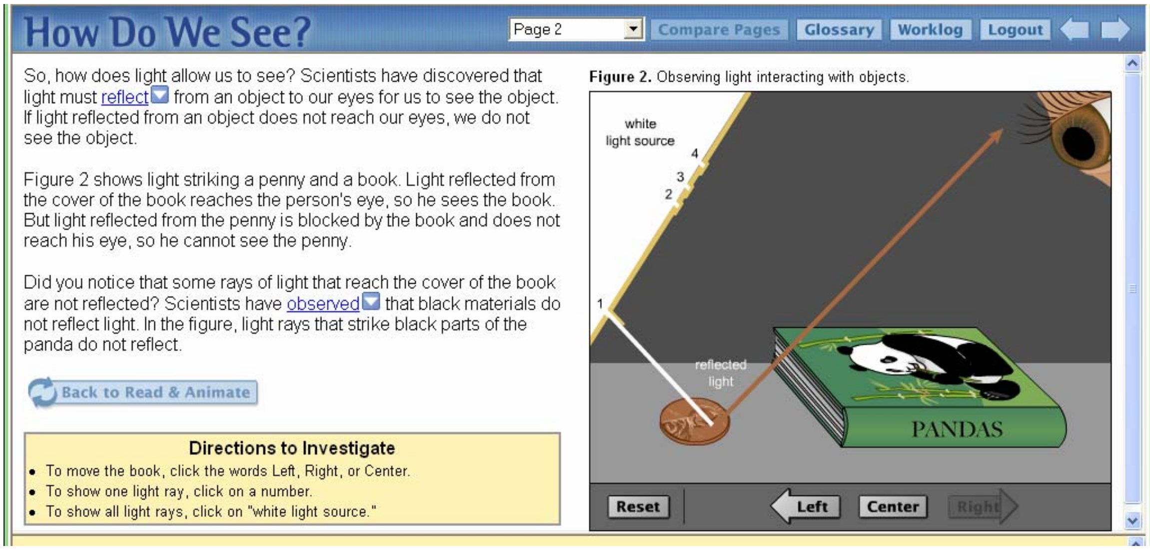

Figure 3.4
The Manipulable Graphic as the reader manipulated it

The reader moved the book to the right, activating the white light source to see if the light reflected to the eye so that the person could see the penny, or if the reflecting light would be blocked by the book.

The Manipulable Graphics offered several affordances which, while listed in sequence, represent overlapping opportunities to construct metarepresentational, syntactic, and substantive knowledge regarding the experimental text. The Manipulable Graphics directs readers to:

- Change key aspects of the graphic which represent the conditions (e.g., amount or direction of light, position or color of object) under which phenomena behave in particular ways. In this way, manipulating the diagram invited readers to study aspects of the graphic that mattered – metarepresentational knowledge that may enable them to interpret the graphic or create their own graphic or mental models of the ideas.

- Observe multiple instances of the behavior of phenomena under a variety of conditions (e.g., light from the same source strikes the book when the book is in left, center, and right positions). These opportunities for multiple observations offered the raw materials that may enable readers to engage in scientific inquiry –

including the knowledge of syntactic structures such as the processes by which scientists discover principles by systematically considering multiple instances, variations, and contrasts in behavior.

- Discover specific relationships or aspects of the behavior of phenomena, their consequences and causes, by explicitly directing readers “to change,” “to move,” “to remove,” “to paint,” and “to see what happens when…” Readers were provided the opportunity to gain conceptual understanding, or substantive knowledge, by testing or refining the ideas that they brought to their reading or that had begun to develop while reading the prose (e.g., their own mental animations of the phenomena depicted in the graphic and described in the prose).

VOCABULARY AND TEXT-TO-SPEECH SUPPORTS

In addition to the affordances that were unique to the Highlight & Animate Condition and the Manipulable Graphics Condition, there were affordances that were common to both conditions: text-to-speech (TTS) and vocabulary supports. Readers could direct the computer to read all, or part, of the prose aloud to them. Thus, TTS offered readers the opportunity to offload the task of word recognition to the computer and allocate their resources to making sense of the text. Vocabulary support was provided in the forms of glossary, synonym, and highlighter tools (see Figure 3.5). Clicking on selected words – underlined and in blue font – produced a pop-up-window glossary with a definition, example sentence, and illustration of the target word. Clicking on the synonym symbol that followed selected vocabulary items produced a pop-up single word synonym. A highlighter symbol appeared in the prose after names of structures of the eye. Clicking on this symbol highlighted – in flashing red – the label for that structure as shown in the graphic. The vocabulary supports invited readers to monitor their own understanding and look up words that interfered with understanding.

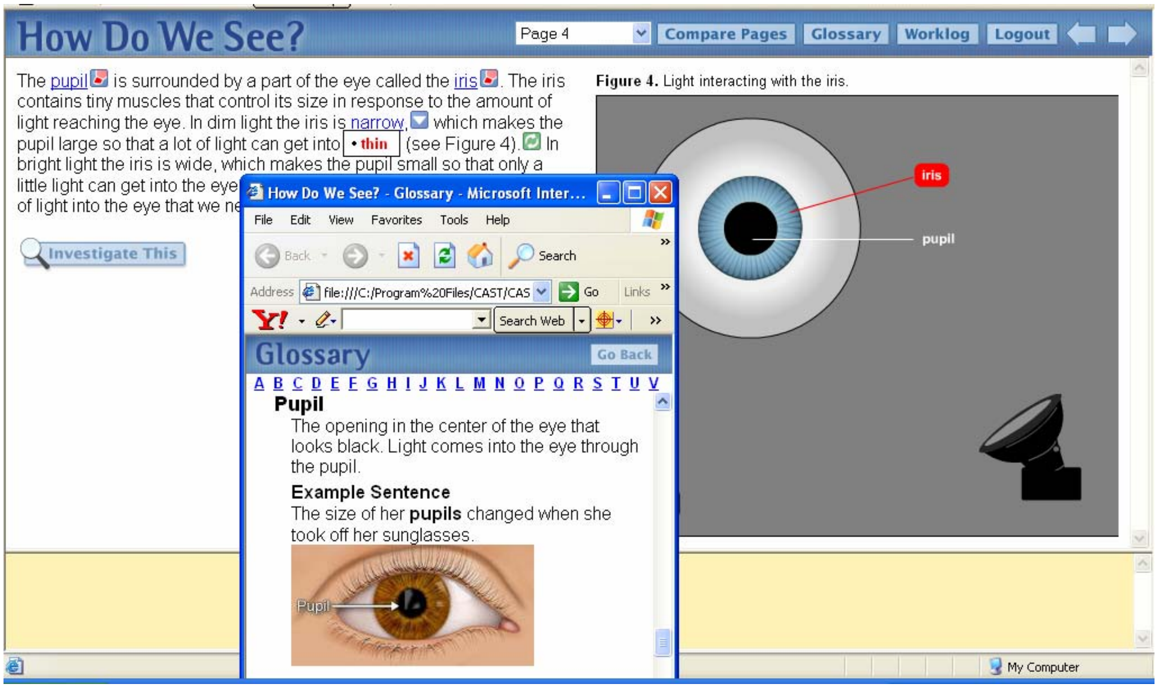

Figure 3.5
Vocabulary supports activated

The glossary has been activated for 'pupil,' producing a large pop-up window with a definition, an example sentence, and a picture of the pupil. The synonym tool has been activated for 'narrow,' producing a tiny pop-up window with the synonym 'thin.' The highlighter tool has been activated for 'iris,' so that the label for iris flashed red.

Measures and Data Sources

Text-specific conceptual knowledge and vocabulary tests sampled entering knowledge about the ideas of the experimental text. These tests were re-administered after participants read the text, providing an objective index of knowledge gained. These measures were used to answer questions regarding the effects of the experimental features. An interview, conducted as participants read the text, elicited verbal reports of readers' understanding of concepts presented in the experimental text. These reader reports of understandings about light and vision provided additional data to address research question one. Activity logs recorded the frequency and patterns of participants' use of features of the digital environment. The data from interviews and activity logs, which constituted readers' transcripts, provided the means to construct qualitative descriptions of participants' interactions with the affordances of the digital environment and the ideas of the experimental text. These data was used to answer research question two, which concerned how the experimental features mediated participants' interactions with the text. Measures and data sources are described in more detail below.

KNOWLEDGE OF THE TOPIC: HOW WE SEE

The *Conceptual Knowledge Test* (see Appendix B) was a 9-item, experimenter-designed, multiple choice measure of understanding of concepts specific to the topic of the experimental text. This test was administered before and after students read the experimental text. Interviewers read the questions and possible responses aloud, as participants followed along, in order to minimize the impact of poor word recognition. Concepts tested included how light interacts with objects (e.g., light is absorbed by black objects, reflected by objects of other colors) and how structures of the eye function to interact with light and allow us to see (e.g., the pupil admits light; the optic nerve conducts the signal to the brain). The pretest suggested that there was plenty of room for growth in participants' understanding of these concepts. To seven of the nine test questions, fewer than half of participants responded correctly. The only item that most participants answered correctly upon entering the study concerned changes in the size of the pupil in response to changes in light.

The selection of concepts to be tested was guided by a scientist's assessment of what were the important concepts of the text. Construction of multiple choice items was guided by the principle that distracters should reflect the developmental characteristics of examinees (Robertson, 2003). Thus, construction of the *Conceptual Knowledge Test* items drew upon the literature regarding children's naïve conceptions, or common sense explanations, about light and vision, as described in detail in Chapter 2. For example, the first question on the test addressed the concept that light enables us to see when it is reflected from an object to our eyes. The distracters for the first question included the 'simple emission model,' a model characteristic of fifth graders' misconceptions about how light interacts with objects and the eye to enable us to see (Langley et al., 1997; Selley, 1996b). On the pretest, the emission model (answer b) was selected (incorrectly) by 54% of participants[6], while the correct model (answer c) was selected by just 26% of participants. The posttest reflected a change in participant's thinking: 65% of participants chose the correct model; 19% of participants still held to the emission model. Another question on the test concerned how we see color. Distracter items included the scientific explanation (b – the stop sign reflects red light to our eyes) and a common sense explanation (d – the stop sign is painted red). On the pretest, the common sense explanation was selected by 55% of participants; the scientific explanation was selected by 36% of participants. On the posttest, the proportions were reversed, with more participants choosing the scientific explanation and fewer choosing the common sense explanation. Five of the nine questions on the conceptual knowledge test also required scientific thinking about the interpretation of graphics.

The *Text-Specific Vocabulary Test* (see Appendix C) was a 10-item, experimenter-designed, multiple choice measure of vocabulary specific to the experimental text. The test was read aloud to participants. The same vocabulary test was administered as participants entered and exited the study. Words were chosen for this assessment, in part, on the basis of research such as that of Beck, McKeown, and Kucan (2002) on vocabulary assessment and instruction. The test included mostly words that were both characteristic of mature language use across domains and applied with nuances specific to the particular domain of science. In retrospect, it was a limitation of this assessment that words were tested out of context. The test may have been more informative if words had been tested in ways representative of the fine distinctions necessary to distinguish the common definitions of the words from their meanings in the experimental text. Ideally, as Pearson, Heibert, and Kamil (2007) suggest, the distracter items would have been constructed in a manner that revealed readers' evolving command of words, from pre- to post-test.

The words chosen for the vocabulary assessment were also among the words that the authors of *How Do We See* deemed necessary to understanding the text and linked to

[6] Information on performance on the conceptual knowledge measure was compiled from all fifth graders who have taken the test: 113 fifth graders have taken this assessment as a pretest; 57 fifth graders have taken it as a posttest.

vocabulary supports. Since there was little contextual support for many of the target words in the prose or graphics of *How Do We See*, I thought readers would have to access the vocabulary supports if they wanted to ascertain their meanings. In order to evaluate readers' use of the vocabulary supports, it was necessary to know if readers needed such support, that is, if there were words whose meanings they did not know. There were; participants entered knowing, on average, about half of the target words. The target words were: absorb, narrow, reflect, sensitive, evidence, investigate, signal, strike, prism, and iris. Items familiar to most participants were evidence, reflect, and absorb.

INTERVIEWS

Each participant engaged in a one-on-one interaction that may be characterized as a 'clinical interview' - "a form of mutual inquiry" (diSessa, 2007, p. 531). The goals of the interview, explicitly stated to each participant, were for the participant to make sense of the ideas of the text and for the interviewer to discover how participants were thinking about those ideas. Interviewers facilitated participants' communication of their ideas by encouraging spontaneous comments and asking open-ended questions. Interviewers followed a closely scripted format that was designed to consistently elicit participants' thinking in a manner that reflected the influence of the experimental conditions, but not the influence of interviewer judgments or instruction on specific concepts. One limitation of this format was that interviewers could not pursue participants' thinking opportunistically. For example, when participants did not address an idea from the text on their own, or did not do so comprehensively or accurately, the interviewer could not investigate the cause of this lapse by directing participants to speak to the missing or inaccurate information. And, the interviewer's encouragement, though neutral, may have been interpreted as agreement with erroneous statements.

Interviewers encouraged spontaneous comments by telling participants, before they read each page, "You can tell me what you are noticing as you work on this page." If participants explored the digital environment silently, interviewers provided 'wait time' until participants finished exploring and went back to reading. When participants commented as they read and activated the Highlight & Animate Feature or manipulated the graphics, interviewers responded with verbal and nonverbal expressions of interest – nods, smiles, glances where participant pointed, “Hmm,” “Ahh,” “I see.” When participants’ spontaneous comments were exclamations (e.g., “Oh!” or “Wow!”), interviewers asked, “What made you say that?” When participants asked questions, interviewers either suggested participants say how they might answer the question, or recorded the question and promised to answer it when they finished reading the text. It is probable that the interviewers’ high level of interest in the participants’ thoughts about the text extended the participants’ interaction with the ideas of the text and set an expectation that participants would engage in comprehension fostering activities.

It was also likely that, for a variety of practical reasons, many participants would have more ideas to communicate than they expressed spontaneously as they read and investigated with the experimental text. They may, for example, think it unnecessary to mention an idea that they and the interviewer must have in common. They may be working to integrate old and new knowledge into a coherent form which cannot yet be easily put into words. Or, they may be unsure what to say if the interview format is different from their familiar script for school discourse. It was possible that participants’ ideas had changed in the course of their reading and investigating. In order to elicit a broader range of participants’ ideas as well as identify changes or developments in participants’ ways of thinking about those ideas, interviewers asked a series of six questions after participants finished working with each page. Participants had the experimental text in front of them as they responded to the interviewers’ questions. Those questions were:

1. What are you noticing on this page?
2. What did you learn from that?
3. How did you figure that out?
4. Was the investigation/animator helpful to you?
5. If yes, how was it helpful? or What in particular, was helpful?
6. Is there anything else that you would like to add?

These interview questions probably prompted some participants to do more spontaneous reflecting than they would have done if they were not asked the questions. Certainly some participants began to keep these questions in mind as they read, since, after a few pages, they began answering the initial questions without being asked. Interviewers responded to participants answers to these questions with expressions of interest, as described above. Interviewers could also re-voice participants' statements, where statements could be repeated verbatim, rather than select particular information to be acknowledged. Participants' responses to the interview questions, as well as the spontaneous remarks they made in the course of reading and using the experimental features, were audio recorded and transcribed. Thus, the interviews supplied a record of all of the understandings about light and vision that readers articulated – coherent ideas and bits of knowledge yet to be integrated, as well as reports of how they came to those understandings – elicited in a highly supportive context.

ACTIVITY LOGS

'Activity' denotes participants' nonverbal interaction in the digital environment. Activities included feature and tool use: activating the Highlight & Animate Feature, looking up words with the synonym tool, highlighter, or glossary, turning text-to-speech on and off, and navigating to other pages, as well as acting on a Manipulable Graphics. Activities also included gestures with the computer mouse: following text as it was read, tracing the trajectory of an element of the graphic (e.g., the path of light through the structures of the eye), or pointing to establish a joint reference with the interviewer (e.g., the referent for "this one") or to illustrate an explanation. These activities were recorded by Camtasia software which captured, in real-time, audio and video format, the computer screen with the moves that participants' made in the context of what they said. Participants' verbal responses to the text in the interview context were synchronized with their concurrent nonverbal interactions with the digital environment. In this way, activity logs helped to clarify readers' words, thus assuring that interpretation of the transcripts was as accurate as possible. For example, a reader's oblique reference to an object (e.g., "this one") or action (e.g., "goes like this") or location (e.g., "over here") became clear when the video record showed where the reader was pointing the cursor while speaking.

Readers' descriptions of scientific phenomenon or explanation of scientific principle could be set in the context of readers' perspectives, such as a series of moves just made to investigate by manipulating the graphic. Together, the data from the interviews and activity logs constituted the readers' transcripts.

Procedures

Participants engaged in the activities of this study over the course three days as outlined in Table 3.4 and the following narrative.

Table 3.4
Timeline for study

Time	Activity
Day 1[7]	• Pretest of conceptual knowledge, • Assessments of reading comprehension and spatial relations
Day 2	• Pretest of text-specific vocabulary, • Assessments of letter-word identification and general vocabulary, • Orientation to the digital environment
Day 3	• Review of features and tools of digital environment, • Reading How Do We See, • Posttest of vocabulary and conceptual knowledge

On Day 1 participants completed the assessments of reading comprehension and spatial ability, as well as the multiple-choice measure of conceptual knowledge about light and vision. Subsequently, participants were randomly assigned to conditions; assignments were checked to assure that amount of participant entering conceptual knowledge was fairly equally distributed across conditions. Two months later, on Day 2, word recognition, general expressive vocabulary and text-specific receptive vocabulary were assessed. Also on Day 2, participants engaged in an individual, hands-on orientation to the digitized environment. Using a scripted protocol (see Appendix D for example), interviewers demonstrated the features of the digital environment specific to the

[7] There was a two-month gap between days 1 and 2. Days 2 and 3 were consecutive.

participant's condition. Interviewers guided the participants to practice using the features in the context of reading a two-page digital text on the topic of optical illusions.

On Day 3, working one-on-one with an interviewer, each participant reviewed the labels, functions, and means of accessing the experimental features and support tools of the digitized environment. After demonstrating mastery of the tools and features, participants read each of the eight pages of "*How Do We See* in their assigned condition. Participants could read aloud independently (interviewers assisted with production of challenging words as necessary) or follow along as the material was read by TTS.

Interviewers made certain that participants in the Highlight & Animate Condition activated each Highlight & Animate symbol as they came to it in their reading, if they did not do so independently. They could return to it as many times as they wanted. Participants in the Manipulable Graphics Condition were prompted to follow each 'direction to investigate' if they did not do so spontaneously. Then, they could continue to engage with the diagram for as long, and in whatever manner, they chose to do so. Only use of the two features that distinguished the conditions – the Highlight & Animate Feature and the Manipulable Graphics – was compulsory. Participants were encouraged, but not required to use the vocabulary supports – glossary, highlighter, synonym tool – or the text-to-speech feature, when they thought these would be helpful.

If, in the course of their reading or investigating, participants exclaimed (e.g., **"Oh!" "Cool!" "Now I get it!"**), interviewers prompted them to expand on their exclamation (e.g., "What makes you say oh!?"). After each page was read, and without cutting short any spontaneous remarks, interviewers asked participants the interview questions with respect to that page. The reading and concurrent interview approximately took 35-55 minutes. The entire session was audio recorded and also recorded via screen-capture software (Camtasia). After reading the entire text, participants completed the text-specific vocabulary and conceptual knowledge posttests. In the following chapter I present the analysis and findings from this data.

CHAPTER FOUR: RESULTS AND DISCUSSION

Recall that the purpose of this research, as stated in the research questions, was twofold: 1) to investigate the effects of the Highlight & Animate and Manipulable Graphics features on participants' knowledge of the topic of the experimental text and 2) to study the nature of participants' interactions with the experimental text in the Highlight & Animate Condition and in the Manipulable Graphics Condition. In other words: to examine both the products and processes of readers' interactions with the experimental text. The analysis of data proceeded in the following manner.

Although the research questions called for the study of participants' experiences within their assigned conditions, it was comparisons between the two experimental groups that often provided a perspective for interpreting the data. So, I first ascertained that these groups were equivalent on measures of knowledge and skills relevant to the tasks that they engaged in for this study. Then, I conducted both quantitative and qualitative analyses to determine the effects of the Highlight & Animate Feature and Manipulable Graphics on knowledge of the topic of the text. Pre-post objective assessments of conceptual and vocabulary knowledge showed that participants in both the Highlight & Animate and Manipulable Graphics Conditions learned. That is, the amount of *knowledge gained* was significant; furthermore, the amount was not significantly different by condition. Transcripts of readers' spontaneous and interviewer-elicited responses to the experimental text revealed additional data regarding participants' knowledge of the topic of the text. Participants in both conditions *articulated knowledge* that consistently and accurately reflected important ideas of the text – and did so to a greater extent than indicated by the objective measures of learning. Participants in the Highlight & Animate Condition articulated the important ideas in a manner that was more complete, relative to their peers in the Manipulable Graphics Condition.

The next phase of the analysis was guided by the claim that the Highlight & Animate Feature and the Manipulable Graphics were designed as unique and complementary affordances to enable readers to meet the conceptual, graphic, and linguistic demands of the experimental text. In parallel lines of inquiry, transcripts were examined to identify trends typical of the experimental groups and variations within and across these groups. Specifically, I sought to a) discover patterns of readers' interaction with the affordances of the digital environment that were unique, and common, to the Highlight & Animate and Manipulable Graphics Conditions, b) examine how readers in the Highlight & Animate Condition and the Manipulable Graphics Condition used these affordances to interact with the concepts, vocabulary, and graphics of the experimental text, and c) develop profiles of individual readers whose use of the affordances of the digital environment did, or did not, facilitate interactions that enabled them to meet the cognitive, linguistic, and graphic demands of the text. These three avenues of inquiry provided insights into how the design of the features of this digital environment, the demands of this conceptually complex, graphic-rich text, and the characteristics of these individual struggling readers could interact in ways that facilitated understanding of the topic of the text.

Assuring Comparable Samples

The analyses of data, as outlined above, called for comparisons between two groups of participants who were randomly assigned to one of two (Highlight & Animate or Manipulable Graphics) conditions. Before reporting the results of the analyses, I provide confirmation that the two experimental groups were comparable on relevant measures, which were described in detail in Chapter 3. Independent samples t-tests that did not assume homogeneity of variance (with respect to small sample size) revealed no significant differences across conditions in participants' performance on the measure of knowledge and vocabulary, reading achievement and other cognitive and linguistic skills relevant to the tasks of this study (see Table 4.1).

Table 4.1
Tests of differences between experimental groups.

Measure[8]	Highlight & Animate mean	Manipulable Graphics mean	Difference	F	Sig.
Gates-MacGinitie	17.9 (11.02)	13.8 (7.1)	4.1	.978	.336
WJ Letter-Word ID	86.3 (8.62)	89.3 (8.49)	-.30	.615	.443
WJ Picture Vocabulary	95.7 (8.76)	89.2 (9.2)	6.5	2.619	.123
WJ Spatial Relations	102.3 (13.1)	111.9 (13.66)	-9.6	2.574	.126
Conceptual Knowledge	3.6 (1.71)	3.2 (1.14)	.40	.379	.546
Vocabulary Knowledge	5.4 (2.01)	6.0 (1.15)	-.60	.669	.424

Chi-square tests appropriate for small sample sizes (Fisher's Exact Test) revealed that differences between the two experimental groups in race and gender were not significant (see Table 4.2).

Table 4.2
Tests of between-group differences in race or gender

Variable	Highlight & Animate	Manipulable Graphicss	Sig.
Race	7 White, 4 African American	7 White, 2 African American	.426
Gender	4 male, 7 female	4 male, 5 female	.535

The finding of no significant between-group differences on these measures increases confidence that any differences found in participants' understanding and interactions with

[8] Gates-MacGinitie scores are Normal Curve Equivalents; normative mean = 50, standard deviation = 21. WJ (Woodcock Johnson) scores are deviation quotients; normative mean = 100, standard deviation = 15. On the experimenter-designed pre-test of conceptual knowledge, nine points were possible; ten points were possible on the vocabulary pre-test.

the text are the result of differences in the affordances of each condition, in the supportive context of the clinical interviews, rather than the result of differences within students.

Measuring Effects on Knowledge

Question 1:
What were the effects of a Highlight & Animate Feature or Manipulable Graphics on participants' knowledge of the topic of the experimental text? That is, after reading the text:

a. How much knowledge did participants gain?
b. How well did participants articulate understandings of important ideas?

KNOWLEDGE GAINED: QUANTITATIVE ANALYSIS OF OBJECTIVE MEASURES

Data Sources and Analyses. As described earlier, objective assessments were used to characterize entering conceptual and vocabulary knowledge, as well as to measure change. The multiple-choice tests – a 9-item measure of conceptual knowledge and a 10-item measure of vocabulary knowledge – were analyzed for evidence of the effects of the experimental conditions on participants' knowledge of the topic of the experimental text. Effects, using these measures, were defined in terms of quantity of *knowledge gained*, or the increase in number of items correct on the posttests, by comparison with items correct on identical pretests. Data were analyzed to determine if there were significant gains from pre- to post-test for each experimental group and to compare gains across conditions. In consideration of the small sample size, nonparametric statistical tests were used.

Conceptual knowledge gained: within groups. Participants in the Highlight & Animate Condition (N = 11) achieved a mean gain of 1.5 (sd = 2.1) correct responses from pre- to post-test of conceptual knowledge (see Table 4.3). Results of the Wilcoxon test indicate that this gain was significant, $z = -2.03$, $p = .04$. There was considerable variation within the group. Seven participants demonstrated gains ranging from 1 to 5 (mean = 2.7) correct responses. Two showed no gain; two lost ground, answering one or two fewer questions correctly. The effect size of the change from pre- to posttest of conceptual knowledge for participants in the Highlight & Animate Condition was moderate, Cohen's d = .7.

Participants in the Manipulable Graphics Condition (N = 9) gained a mean of 2.6 (sd = 1.7) items correct from pre- to post- conceptual knowledge test (see Table 4.3). The Wilcoxon test showed this gain to be significant, z = -2.54, p = .01. No one lost ground; one made no gain; eight made gains ranging from 1 to 5 (mean = 2.9) more items correct. The effect size of the change from pre- to posttest of knowledge for participants in the Manipulable Graphics Condition was large, Cohen's d = 1.53.

Table 4.3
Knowledge gained on 9-item Conceptual Knowledge Measure

Condition	Pretest Items Correct: Mean (SD)	Posttest Items Correct: Mean (SD)	Range of Changes from Pre- to Posttest	Gain: Mean (SD)	Effect Size
Highlight & Animate	3.6 (1.6)	5.1 (2.1)	-2 - 5	1.5*[9] (2.1)	.70
Manipulable Graphics	3.1 (1.2)	5.7 (1.2)	0 - 5	2.6** (1.7)	1.53

Vocabulary knowledge gained: within groups. The Highlight & Animate group gained an average of 1.3 (sd = 1.2) items correct from pre- to posttest of vocabulary knowledge (see Table 4.4). This gain is significant on the Wilcoxon test, z = -2.51, p = .01. The range in gain on the vocabulary measure within the Highlight & Animate group was from 0-3. Two participants gained 3 items; two gained 2 items; six gained 1; one gained none. The effect size of the vocabulary gain for the Highlight & Animate group was large, Cohen's d = 1.06.

For the Manipulable Graphics group, the average pre- post gain in vocabulary knowledge was .88 (sd = 1.4) (see Table 4.4). This gain is not significant on the Wilcoxon test, z =

[9] * $p \leq .05$
** $p \leq .01$

1.63, p = .1. The range in vocabulary gain within the Manipulable Graphics group was 0-3 additional items correct. The effect size for pre- to post change in vocabulary was medium, Cohen's d = .64.

Table 4.4
Knowledge gained on 10-item Vocabulary Knowledge Measure

Condition	Pretest Items Correct Mean (SD)	Posttest Items Correct Mean (SD)	Range of Change from Pre- to Posttest	Gain Mean (SD)	Effect Size
Highlight & Animate	5.5 (1.9)	6.7 (2.7)	0-3	1.3** (1.2)	1.06
Manipulable Graphics	6.0 (1.2)	7.0 (1.2)	0-3	.88 (1.4)	.64

Conceptual and vocabulary knowledge gained: comparison across groups. Results of a Mann-Whitney test show that the differences between the Highlight & Animate and Manipulable Graphics Conditions in conceptual knowledge and vocabulary gained are not statistically significant. For the conceptual knowledge test, Mann-Whitney U = 35.45, z = -1.084, p = .295; for the vocabulary test, Mann-Whitney U = 35.50, z = -721, p = .492.

Summary of analysis of objective measures and next steps. To summarize, participants in both the Highlight & Animate and Manipulable Graphics Conditions made gains from pre- to posttest of conceptual knowledge that were statistically significant and moderate to large in effect size. Gains in vocabulary knowledge were moderate to large in effect size and statistically significant for the Highlight & Animate Condition, but not for the Manipulable Graphics Condition. Between-group differences in conceptual and vocabulary knowledge gained were not significant. The analysis of *knowledge gained* provided evidence that after reading the experimental text, participants in both conditions learned – and learned comparable amounts – about light and vision. The next move in the analysis of the effects of the Highlight & Animate and Manipulable Graphics Conditions on knowledge of the topic of the experimental text was a qualitative study of *knowledge articulated* by participants as they read the text.

There were several reasons to seek additional data with which to examine the effects of the Highlight & Animate and Manipulable Graphics Conditions on learning. Foremost among these reasons was concern regarding the limitations of the multiple choice measures discussed in Chapter 3.

It should also be noted that gains on the Test of Conceptual Knowledge, while statistically significant, were, from an educational perspective, modest. Could readers of *How Do We See* have gained some knowledge about light and vision than was not represented in their responses to the objective measure? It was possible that readers had developed partial understandings that were not represented in the closed sets of multiple choice responses. Perhaps, in the interview context, readers expressed understandings other than those targeted by the limited number of multiple choice questions.

Characteristics of the readers and of the language and graphics of test items also argued for additional data on learning. For these struggling reader participants, an incorrect response on a prose-type multiple-choice item may have indicated difficulty interpreting the language of the question, rather than understanding the concept tested. Alternatively, success on graphic-type multiple choice items may have indicated that the reader remembered the activity with the graphic rather than that the reader understood the phenomena. For all of these reasons, it was necessary to look more directly at knowledge about light and vision, by looking at readers' transcripts and evaluating the statements that they made as they interacted with the text and the interviewer.

KNOWLEDGE ARTICULATED: QUALITATIVE ANALYSIS OF TRANSCRIPTS

Data Sources. Transcripts, consisting of verbalizations produced in the interviews and nonverbal moves from the activity logs, provided data to complement the multiple-choice items of the objective assessments. Recall that transcripts included (a) readers' *ideas spontaneously expressed* as they engaged with the text as well as *ideas elicited* by the interviewer after readers finished working with each page (the text was still accessible to them), annotated with (b) accounts of each instance of readers' activation of an experimental feature, vocabulary tool, or TTS support as well as each gesture on the computer screen (with mouse). Transcripts showed that interviewers adhered strictly to the interview protocol. The wording of questions and directions was nearly identical across the four interviewers. This fidelity to the explicitly scripted, written interview protocol provided assurance that participants' experiences were comparable across interviewers and that their verbal responses and nonverbal moves were mostly prompted by identifiable factors relevant to this study, in particular, their entering knowledge, interactions with the digital environment, and the interviewer's direction.

Analysis of data. Effects on participants' knowledge of the topic of the experimental text, as revealed in readers' transcripts, were defined in terms of quality of *knowledge articulated*. The quality of knowledge articulated was determined by the degree to which statements from readers' transcripts reflected key ideas of *How Do We See*, as identified by an expert. (For examples of research in which readers' responses to text are matched against an expert's template, see Chambliss & Murphy, 2002 and Chi, De Leeuw, Chiu & LaVancher, 1994.) A scientist conducted an analysis of each screen (page) of the text, except page 5, which was a mid-text, very brief summary of the preceding pages. On the basis of the scientist's analysis, I identified thirteen 'important ideas' (see Table 4.5).

Table 4.5
The important ideas in *How Do We See*

Page	Idea
1	We need light to see; we cannot see without light
2	Light reflected from an object enables us to see the object
	When light reflected from an object is blocked, we cannot see the object
	Light is not reflected from materials that are black
3	Light enables us to see when it enters the eye at the pupil

Page	Idea
	Light interacts with structures of the eye – the retina and optic nerve
	The brain interprets signals from the light to tell us what we see
4	The iris regulates the amount of light that enters the eye through the pupil
	The pupil admits more light in dim conditions, less light in bright conditions
6	Light is absorbed or reflected by materials in proportion to its depth of color
7	Light is composed of colors
	We see the color of light reflected from object; other colors of light are absorbed
8	We see colors when specialized structures of the eye interact with light

Next, I examined each participant's transcript to identify their thirteen 'best statements, or the propositional clusters (see van Dijk & Kintsch, 1983), that most closely aligned with the thirteen important ideas in Table 4.5. Each one of participants' best statements was then characterized on the basis of a four-point rating scale (see Table 4.6). For a report of ratings of best statements for each important idea by condition, see Appendix E.

Table 4.6
Rating scale for participants' best statements

Rating	Label	Description
0	Missing	The important idea was not addressed – no best statement.
1	Inadequate	The important idea was addressed inaccurately, or with only peripheral details or labels, or so incompletely that a judgment of accuracy could not be made, or participant expressed confusion.
2	Adequate	The best statement provided only a mostly accurate[10] description of details of phenomena as depicted in examples in the text, but without a clear description of relationships among phenomena.
3	Complete	The best statement included a mostly accurate explanation of phenomena, cause-effect relationships, statement of scientific principle,[11] or novel example that shows application of principle.

[10] Participants' statements are referred to as 'mostly accurate' since it was not uncommon for participants to produce one or more partially inaccurate statements in the process of refining their ideas.

The rating scale was developed in view of scientific practices of reasoning and standards of communicating (Langley, Ronen, & Eylon, 1997; Schwab, 1964), which are reflected in the discussion of the conceptual, linguistic, and graphic challenges of science text in Chapter Two. With respect to conceptual challenges, the ideal 'best statement' would accurately reflect substantive knowledge (Schwab, 1964). That is, participants would produce descriptions of the behavior of light and the process of vision that were *accurate*, or consistent with the scientific explanations of the text, rather than the naïve conceptions of everyday experience. Regarding the linguistic challenges, best statements should, optimally, reflect the theoretical explanation structure (Veel, 1997) of the experimental text. So, participants would describe the specific examples of the behavior of light in the text not as isolated events, but as evidence in support of claims about *scientific principles*.

An excellent best statement would demonstrate evidence of interpreting the directing codes as well as the depicting codes (Weidenmann, 1994) of the graphics. In other words, participants would describe the *important*, rather than peripheral, details of the physical appearance of objects depicted in the graphics. And, they would interpret the actions shown in the animation, in terms of the *relationships* to be discovered by comparing and contrasting the multiple perspectives provided by the animation and manipulation. Note that understandings that were constructed in a manner consistent with these guidelines would be likely to reflect readers' integration of information from graphics and prose (where the reader was not simply reporting prior knowledge). Rubrics were created to apply these general guidelines specifically to each important idea of How Do We See (see Appendix E). A second rater also evaluated all of the participants' best statements. Inter-rater reliability as determined by the Kappa coefficient was .899. Disagreements were resolved through discussion.

Quality of knowledge articulated. Visual inspection of the ratings of quality of knowledge articulated indicated that, across conditions, participants usually identified the important ideas and often did so accurately. Participants in the Highlight & Animate

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[11] Where participants provided a complete best statement that was lifted **verbatim** from the text, the best statement was characterized as 'adequate' rather than 'complete,' since it was likely that a direct quote reflected, at best, a tenuous grasp of the concept expressed, or at worst, a lucky guess.

Condition identified, on average, all but 10% of the important ideas; participants in the Manipulable Graphics Condition identified all but 15% (see Figure 4.1). This finding suggests that an analysis of the knowledge that readers articulated may reasonably be structured around these important ideas. Seventy-one percent of the best statements produced by participants in the Highlight & Animate Condition were accurate (adequate or complete); 65%, in the Manipulable Graphics Condition. This finding, coupled with the previous finding, indicated that the digitized text must have presented the important ideas in ways that facilitated readers' articulation of knowledge about the topic, since interviewers did not direct readers to consider any particular idea.

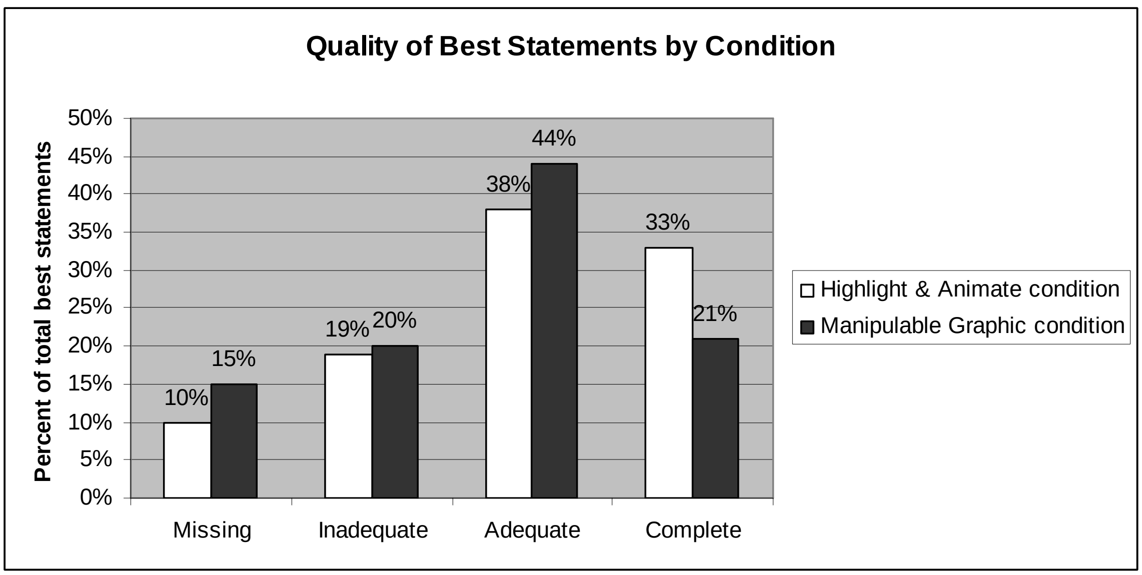

Figure 4.1
Quality of knowledge articulated in best statements

The statistical analysis of the quality of best statements showed that participants in the Highlight & Animate Condition were more likely than their peers in the Manipulable Graphics Condition to produce the highest quality of best statements (see Figure 4.1). Chi-square tests appropriate for small sample sizes (Fisher's Exact Test) revealed that differences between the two experimental groups were statistically significant with respect to the proportion of *complete* best statements produced ($p=.05$).

A plausible explanation for this finding is as follows. The guidelines for rating best statements, consistent with standards for scientific communication, privileged those remarks that included a big idea – an explanation or statement of scientific principle. While big ideas were often stated explicitly in the prose, they could not always be easily inferred from the phenomena depicted in the graphics. Participants in the Highlight & Animate Condition were prompted – by the highlighting – to review selected prose each time they activated the Highlight & Animate Feature. They would have had opportunity to review, and build their knowledge of some of the big ideas. (Note that *half* of the important ideas were stated in the prose that was highlighted, while its corresponding graphic was animated, in response to readers' activating the Highlight & Animate buttons.) Participants in the Manipulable Graphics Condition, who were mostly directed to the graphics, might not have spent sufficient time studying the prose to gain a foothold in the important ideas presented there. This hypothesis will be explored further in the upcoming analysis of readers' interactions with the affordances of the digital environment.

To summarize the findings for question 1 regarding the effects of the Highlight & Animate and Manipulable Graphics Conditions on knowledge of the topic of the experimental text: the analysis of (a) pre-post multiple choice assessments of conceptual and vocabulary knowledge, and of (b) spontaneous responses to text and elicited statements prompted by an interviewer, revealed that the digital environment had a positive effect. Readers in both conditions demonstrated receptive gains in knowledge about light and vision and expressed that knowledge consistently and often accurately. They expressed this knowledge in more sophisticated form more often in the Highlight & Animate Condition. These findings lend credence to the contrast that interviewers reportedly noted between participants in this study and those in the Intervention Study (described in Chapter 1). In the Intervention Study readers had access to both the Highlight & Animate Feature and the Manipulable Graphics, but generally focused their efforts on manipulating the graphics. In contrast, in this study, while the Manipulable Graphics prompted readers to interact productively with the experimental text, readers who had not seen the Manipulable Graphics and were required to use the Highlight &

Animate Feature, used the Highlight & Animate Feature productively. In fact, the Highlight & Animate Feature was associated with the production of knowledge that reflected the integration of ideas from prose and graphics. I now describe the processes by which participants developed and reported that knowledge.

Describing Interactions with the Digital Environment

Question 2

How did the Highlight & Animate feature or the Manipulable Graphics mediate participants' interaction with the experimental text? That is:

a. How did participants use the affordances of the Highlight & Animate Condition or the Manipulable Graphics Condition?
b. How did participants meet the conceptual, linguistic, and graphic demands of the experimental text in the Highlight & Animate Condition or in the Manipulable Graphics Condition?
c. How did participants within each condition vary in their use of the affordances of the Highlight & Animate feature or the Manipulable Graphics and in their meeting the conceptual, linguistic, and graphic demands of the text?

Overview

In the pages that follow I describe readers' interactions with the experimental text using three parallel, fine-grained analyses of readers' transcripts. The first, *analysis of affordances*, asked how readers used the affordances that were unique to each condition – the Highlight & Animate Feature and Manipulable Graphics – as well as the tools that were common to both conditions – TTS and vocabulary supports. The purpose of this analysis was twofold: 1) to characterize and contrast the effects of the Highlight & Animate Feature and Manipulable Graphics on the moves that participants in each condition made and 2) to ascertain if participants used the unique and common affordances as expected. This analysis has implications for the design of supportive digital reading environments as well as instruction with static texts. The second, *analysis of ideas*, asked how readers interacted with the ideas of the text in each condition. The purpose of this analysis was to ascertain if the affordances that were designed to enable readers to meet the challenges of the experimental text actually worked as anticipated. This analysis has implications for the design of both digital reading environments and instruction to accompany texts presented in such environments. The final, *analysis of individual experiences,* asked how individuals within conditions varied in their interactions with the text. That is, how did characteristics of individuals interact with the demands of the text and the affordances of the environment? This analysis, which has implications for customizing the design of environments and instruction to meet the needs of individual readers, will be presented in the form of individual case studies in Chapter 5.

Recall that the analyses of readers' transcripts developed to answer research question two were guided by the claim that the Highlight & Animate Feature and Manipulable Graphics were designed as unique and complementary affordances to enable readers to meet the demands of graphic-rich science text. The analyses began, as did the design of the study, with consideration of the demands of the text and the affordances of a digital environment that could support readers learning from that text. Those considerations are reviewed now.

The Demands of the Text. As described in Chapter 2, the demands of text that were of interest in this study were of three types: conceptual, linguistic, and graphic. It was anticipated that readers would need support to learn those concepts that were outside of their own experience, abstract, or in conflict with naïve conceptions about light and vision that are typical of the participants' age group. Indeed, the pretest of conceptual knowledge confirmed that readers entered the study with minimal prior knowledge of the concepts of light and vision that were addressed in *How Do We See*. The linguistic feature of interest in the experimental text was the specialized vocabulary, specific to the domain of science and necessary for a discussion of light and vision. The pretest of text-specific vocabulary sampled readers' knowledge of some of these words and confirmed that they were not all within readers' lexicons. Graphics played a prominent role on nearly every page of *How Do We See,* providing visual representations of structural relationships, dynamic functions, and abstractions. Since these graphics were complementary to, rather than redundant with, the prose, it was crucial that readers integrate information from prose and graphic. Previous work with this graphic-rich text had shown that upper elementary readers did not work across the graphic and prose to integrate the complementary verbal and visual representations. One of the lines of inquiry in the close analysis of reader transcripts was to discover how readers interacted with the ideas of the text with respect to the cognitive, lexical, and graphic demands. The approach to that analysis will be described shortly.

The Affordances of the Digital Environment. In response to the anticipated demands of the experimental text reviewed above, a digital reading environment was designed to support readers to meet those demands. The primary components of the digital environment were a Highlight & Animate Feature and Manipulable Graphics. To review, the Highlight & Animate Feature directed readers to an important idea by highlighting its verbal representation in the prose and facilitated interpretation of its visual representation by animating the graphic. The simultaneous highlighting and animation juxtaposed the complementary information to be integrated across prose and graphics. The Manipulable Graphics Condition offered a diagram that could be manipulated. *Directions to Investigate* told the reader how to change certain aspects of phenomena depicted in the graphics. Readers could investigate the relationships between the change-able aspects of phenomena. Or they could seek to discover general principles of the behavior of the phenomena, which were explained in the prose. Readers were assigned to conditions in which they used only the Highlight & Animate Feature or the Manipulable Graphics so that the separate effects of these features could be observed. Use of the Highlight & Animate Feature and Manipulable Graphics was compulsory. (In an earlier study of this digital environment – the Intervention Study described in Chapter 1 – participants could use both the Highlight & Animate Feature and Manipulable Graphics, though their use was optional.) Tools embedded in the digital environments in both the Highlight & Animate and the Manipulable Graphics Conditions included text-to-speech and vocabulary support. Both of these supports were optional; readers could access them as needed. TTS read the text aloud, allowing readers to devote their resources to comprehension. Vocabulary supports clarified the meanings of words, inviting readers to ensure their own understanding of the selected words.

Readers' Interactions with the Affordances of Each Condition

In the analysis of affordances, participants' use of the affordances of each condition was characterized through the processes of 1) reviewing each participant's transcript (interview and activity log) to create a comprehensive yet succinct chronological description of the verbal and nonverbal moves that each participant made on each page of the text and 2) identifying trends in interactions with the digital environment across participants within each condition. The accounts of reader moves within the Highlight & Animate Condition noted frequency and context of each instance of activating the Highlight & Animate Feature, relative amount of time spent on each Highlight & Animate opportunity, and the general nature of related moves and accompanying comments. In the upcoming analysis of ideas I attend to the specific content of participants' comments and the apparent effects of reader moves on participants' success in articulating the important ideas of the text. Accounts of reader moves in the Manipulable Graphics Condition included patterns and purposes of manipulating each graphic, length of investigation, and the nature of related moves and accompanying comments and the context in which they occurred. For all participants, descriptions of interactions with the affordances also considered the frequency of use of the vocabulary supports and TTS.

READERS' USE OF THE HIGHLIGHT & ANIMATE FEATURE

Readers in the Highlight & Animate Condition seemed to experience the text as a scripted sequence of short, integrated, multi-media tutorials on the principles regarding light and vision. They began their work on each page by reading the prose. When they came to a Highlight & Animate symbol, readers interrupted their reading, as required, to activate the Highlight & Animate Feature. (There were 1-3 Highlight & Animate symbols per page, each located after a statement of an important idea.) In response to the simultaneous highlighting and animation that the Highlight & Animate Feature produced, readers often spontaneously reviewed the highlighted sentence and examined the corresponding graphic. Evidence that readers reviewed the critical information in the highlighted sentence could be found in their silent pauses, rereading the sentence aloud or ‘sotto voce,’ guiding a cursor over the words of the highlighted sentence, quoting from the text, and commenting on the ideas expressed there. It was apparent that readers examined the graphic when their cursors alighted on, or circled, the portion of the graphic that the animation featured and when they commented on the graphic. After reviewing the information provided by the Highlight & Animate Feature, readers returned to read the prose until interrupted by the next Highlight & Animate symbol.

All but two of the participants made spontaneous comments while reading about the ideas highlighted in the prose, and/or animated in the graphic, on as few as one and as many as all six pages containing Highlight & Animate opportunities. Comments included exclamations, quotes and paraphrases of highlighted words, descriptions of the graphic, summaries of ideas from the prose and graphic, explanations, statements regarding confusion, and questions. In the following examples of participants’ spontaneous comments and their moves in interacting with the text, each reader has read page 2 to the point of activating the Highlight & Animate symbol following the sentence: *But light reflected from the penny is blocked by the book so, book and does not reach his eyes, so he cannot see the penny* (see Figure 4.2).

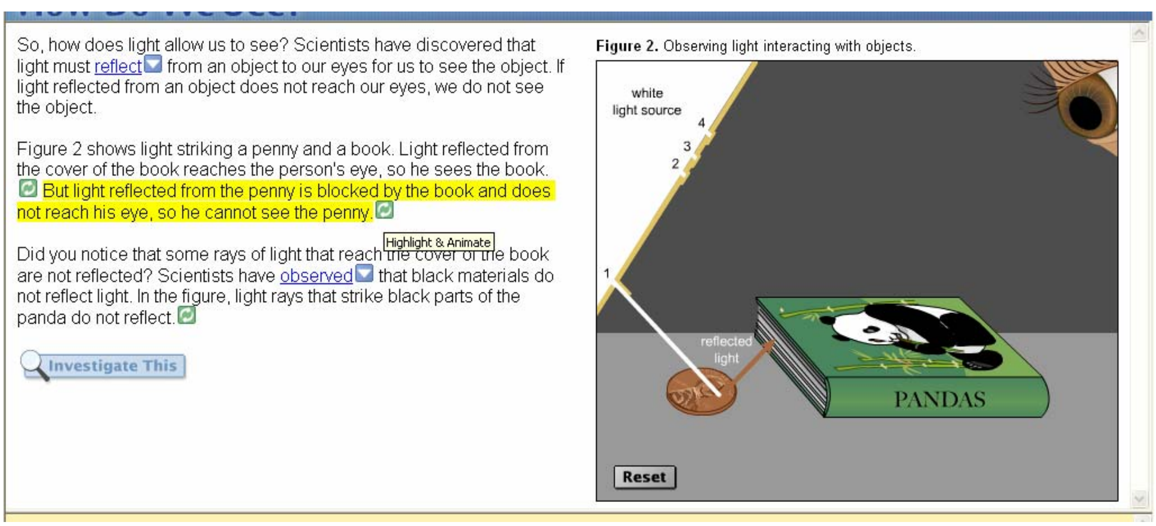

Figure 4.2
Page 2 of *How Do We See* in the Highlight & Animate Condition

As the sentence was highlighted, the graphic showed light traveling from its source to strike a penny, reflecting off the penny, and being blocked by a book from traveling further. The participants responded:

> **Sallie: Oh sweet! Look.**

Impressed by the animation, Sallie re-activated the Highlight & Animate symbol.

Mary traced the words with her cursor and then moved her cursor over the eye and the penny in the figure. She summarized what she figured out:

> **Mary : Oh, so he can't see the penny. He can't see that penny.**

Jillian extended the example described in the prose and shown in the graphic with her own (correct) hypothesis of what would happen under different conditions, but she was confused about an important point:

> **Jillian: I knew it! If that book was moved, then maybe he would see it. But how can the book reflect up to that? Cause, well, maybe it's a shiny book? I don't know…**

Though readers were required to activate each Highlight & Animate symbol once, all readers activated some of the fourteen Highlight & Animate symbols more than once, on their own initiative, either in the course of their reading, or to illustrate their responses to the interview questions that followed their reading. Thus, readers reviewed the material multiple times. Readers generally reported that they found the Highlight & Animate Feature to be helpful in understanding the text. In the following typical example, Allie had read page 2 and activated all the Highlight & Animate symbols (Appendix A shows each Highlight & Animate opportunity for page 2), studying the text silently for 10-12 seconds after activating each Highlight & Animate symbol. Then, in response to the interviewer's questions, she used the Highlight & Animate Feature to illustrate what she noticed in the animated graphic and then returned to the highlighted words to confirm what she learned.

> Interviewer: So, what did you notice?
>
> **Allie: Um, well when I clicked on that one** (re-activated 3rd Highlight & Animate symbol) **it just had one line to the pan, to the book** (illustrated

her statement - followed path of light with cursor from source to panda on book)**, and then when I clicked on that one** (re-activated 2nd Highlight & Animate symbol) **there was just one to the penny and the book** (again, illustrated her idea - followed path of light from source to penny to book)**. And when I clicked on that one** (re-activated 1st Highlight & Animate symbol) **there's only two and three** (clarified this reference by pointing to light sources numbered '2' and '3') **that looked at the book** (demonstrated by followed paths of light to book) **and then, and then went to the eye** (followed to eye)**.**

Interviewer: And what did you learn?

Allie: That… whatever you look at, if it doesn't reflect then you can't see it.

Interviewer: Hmm. How did you figure that out?

Allie: Well I remembered that from before (as she guided her cursor along the previously highlighted words).

Interviewer: Was the animator helpful to you?

Allie: Uh huh.

Interviewer: How did it help you?

Allie: Like I said before it would highlight the most important things so then I would know like the most important thing.

In general, then, readers in the Highlight & Animate Condition reviewed selected – highlighted and animated – messages in both prose and graphic forms, in fairly equal measure and often in an integrated fashion, both in the course of their reading and in response to interview questions. Evidence from transcripts showed that participants often used the Highlight & Animate opportunities as designers intended: attending to specific structures, functions, and phenomena that were important to interpreting the graphic, identifying and reviewing important ideas in prose, and referring to the graphic at the appropriate time as well as tacking between the highlighted prose and animated graphic. The effect of these moves on readers' ability to articulate the ideas of the text will be reviewed shortly.

READERS' USE OF THE MANIPULABLE GRAPHICS FEATURE

The experience of participants in the Manipulable Graphics Condition might be characterized as alternating between the rather daunting task of reading large chunks of challenging text and the considerably more engaging process of figuring out what might be learned by manipulating the parts of a graphic. Readers began their work on each page of the experimental text in the Manipulable Graphics Condition by reading straight through the prose. With the exception of one reader, participants read all of the prose on a page without comments or questions, without interruption or pause, and without verbal or gestural reference to the adjacent graphic. After reading the prose, participants moved immediately to read the *Directions to Investigate*. After reading the directions, participants began their (required) investigation of the graphic.

In their investigations, readers independently activated all aspects of the graphic that were readily visible, easily accessible (e.g., by clicking once), and relatively intuitive (apparent without directions). Participants generally needed the interviewer's guidance to do steps of the investigation which, while they had been included in the *Directions to Investigate*, were not intuitive from a glance at the graphic, either because they were multi-step or, perhaps, unpredictable (e.g., click the light source twice to see if it reaches the eye; drag the iris off the eye). Readers were free to structure their own investigation of the graphic. So, their investigations varied considerably in organization, length, and purpose. For example, some readers, who found that two aspects of a graphic could be changed, held one aspect constant while systematically changing the other. Other readers never adopted such a systematic approach. Some investigations were moderately lengthy and thorough, some were just lengthy. Readers' purposes in investigating the graphic ranged from developing conceptual relationships (e.g., explaining the behavior of phenomena in terms of the big ideas), to establishing relationships between events (e.g., describing patterns observed in the behavior of phenomena), to figuring out what could be done with the Manipulable Graphics (e.g., discovering the consequences of each possible action on the figures).

The following examples of investigations are drawn, again, from page 2 (see Figure 4.4), which shows that light must be reflected from an object to a person's eyes for the person to see the object. In the investigation on page two, light from four different sources can be directed at a book and a penny on a table. The book can be positioned left, right, or center on the table. Whether or not a person close to the table sees light reflected from the cover of the book or the penny, depends on where the light strikes these objects, which, in turn, depends on the position of the book relative to the light source. Note that the *Directions to Investigate* tell the reader how to manipulate aspects of the figure (e.g., 'To move the book, click the words Left, Right, or Center'). The directions do not guide the reader in structuring the investigation either explicitly, by stating what moves the reader should make and in what order, or implicitly, by declaring a purpose for the investigation. Expecting that readers would bring different knowledge and experiences to their interactions with the text, designers wanted readers to be able to test their own ideas, perhaps against those set forth in the prose, without constraint.

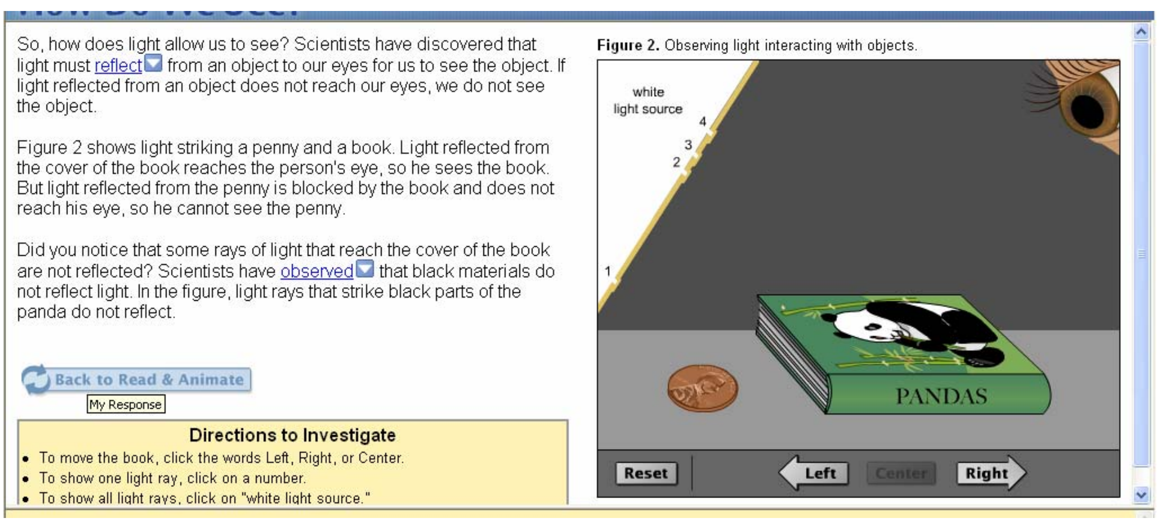

Figure 4.3
Page 2 of *How Do We See* in the Manipulable Graphics Condition

Kevin's investigation was systematic and efficient. His report of what he learned suggested that his purpose was conceptual - to provide an explanation of the behavior of light in terms of the big idea that we need light to see. His investigation looked like this:

Moved book left, activated light sources 2, 4, 3, 1

Moved book right, activated light sources 1, 2, 3, 4

Moved book left, activated light sources 1, 2, 3, 4

Moved book to center, activated light sources 1, 2, 3, 4

Interviewer: So what did you learn?

Kevin: That if light doesn't touch your eye, you can't see what is on it.

Sarah's investigation was not thorough or systematic; she tested just one-third of the possible combinations of light sources and book positions. Her description of what she learned addressed only one of those variables, the choice of light source, without consideration of the position of the book. Her purpose seemed to be to describe a pattern of events discovered – which light sources, when activated, would send light to the pupil. She reported whether or not each light source tested hit its mark – the 'middle' of the eye. Unlike Kevin, she did not say why it was important for the light to reach the pupil. Her investigation looked like this:

Moved book left, right, activated light sources 3, 2, 4, 1, 3

Moved book right, left, center, activated light source 3.

Interviewer: What did you learn?
Sarah: If you click on the number that's in the middle, then it'll go right to the eye. Like…

Activated light source 3: **as you see if you click that one it goes right to the eye.**

Activated light source 4: **This one, this one just stops.**

Activated light source 2: **This one goes… like not to the middle though**.

Activated light source 1: **And this one stops at the book.**

Sarah: Um, like now I know like after you click on something… and you want it to reflect to the eye in the middle then it has to be in the middle of something, and if not it will go like to the sides.

Robert's investigation was brief (though many of his investigations on other pages were exceedingly long), unsystematic and resulted in a conclusion that was consistent with the nature of his investigation. His purpose seemed to be procedural - to find out what effects could be produced when he manipulated different aspects of the figure.

> Moved book left, activated light source 2,
>
> Moved book right, activated light source 4,
>
> Moved book to center, activated light source 3, 3 again, 1, 1 again.
>
> **Robert: I'm done with this page.**
>
> Interviewer: What did you notice?
>
> **Robert: Um, that there's light reflecting everywhere because there's light reflecting whomp, whomp, and then it's going like whoosh, all over the place.**

Half of readers in the Manipulable Graphics Condition spontaneously narrated their own investigations; half spoke of their investigations only when prompted by the interviewer's questions. Spontaneously and in response to the interviewer's questions, readers labeled their own moves, provided a 'play-by-play' of the actions their moves produced, described changes to objects in the graphic, speculated on the cause of those actions and changes, and identified relationships among phenomena. They also noted puzzling events, made connections to their own experiences, compared their own ideas to the events of the investigation, and, occasionally, predicted what might happen under other circumstances. Readers often revisited the investigation to illustrate their interview responses with examples from the graphic. There is no evidence that readers returned to review the prose, though information that may have been remembered from the prose sometimes appeared in readers' remarks about their investigation.

In general, then, participants in the Manipulable Graphics Condition focused heavily on the aspects of the graphic to which they were directed by the investigation opportunities and, in the course of their investigations and subsequent interviews. They provided scant evidence of attending to ideas from the prose. They did not quote or reread the prose aloud, or pause to review it silently. They seldom made reference to ideas that were mentioned in the prose, but not also depicted also in the graphic. Though readers generally reported the investigation was helpful, evidence from the transcripts suggests that they did not fully exploit the affordances of the Manipulable Graphics. That is, participants manipulated the aspects of the graphic as directed by the *Directions to Investigate* and the interviewer. However, their investigation, when not purposefully structured, often did not provide opportunities to observe multiple instances of the behavior of phenomena under conditions that were systematically varied so as to highlight particular relationships or illustrate specific concepts. The extent to which the investigations that participants engaged in enabled them to meet the challenges of the experimental text will be explored shortly.

READERS' USE OF TTS AND VOCABULARY SUPPORTS

Though readers in both conditions had access to the same vocabulary supports and TTS, they used them to considerably different degrees. Since, as established early in this chapter, there were no significant differences in readers' incoming vocabulary knowledge or reading achievement, differences in use of TTS and vocabulary supports may be attributed to the patterns of interacting with the experimental text fostered by the Highlight & Animate Feature and Manipulable Graphics. Readers in the Highlight & Animate Condition requested that 36% of the prose be read to them (by TTS), while readers in the Manipulable Graphics Condition requested TTS assistance with 64% of the prose. It is likely that readers in the Highlight & Animate Condition used TTS less for several reasons. It would simply not be convenient to stop TTS each time it was necessary to activate a Highlight & Animate symbol. Perhaps they found reading prose in short segments punctuated by the Highlight & Animate symbols to be a more manageable task than reading a whole page of prose as those in the Manipulable Graphics Condition did. Also, the intermittent appearance of an animated graphic that complemented the ideas of the prose provided readers who used the Highlight & Animate Feature with contextual cues to support their reading of the prose. Readers in the Manipulable Graphics Condition, who were not directed to note the important ideas in the prose, nor to the connections to the animated figure, may have felt overwhelmed and offloaded the task of reading to TTS.

Readers in the Highlight & Animate Condition accessed vocabulary supports three times more frequently than those in the Manipulable Graphics Condition. Each key word had multiple types of supports (glossary, highlighter, synonym tool). Readers sought different types of definitions for a word by activating symbols embedded in the prose. On average, for each key word, 48% of those in the Highlight & Animate Condition looked it up, while 21% of participants in the Manipulable Graphics Condition sought a synonym, illustration, or definition for the word. Figure 4.4 shows this disparity between conditions in the amount of vocabulary support that participants sought. It is not likely that the experimental groups had disparate needs for vocabulary support; they entered the study with comparable vocabulary pretest scores. It is possible that as the Highlight & Animate Feature prompted readers to review the prose, it established the importance of information to be found in prose and offered opportunities to activate vocabulary tools embedded in prose and, consequently, to reflect on understanding of vocabulary. The Manipulable Graphics Feature had the effect of focusing readers on the graphic, which may have diminished the relative importance of the prose as well as the opportunities to monitor vocabulary comprehension. Consistent with minimal time and attention to prose, only one reader ever interrupted her reading to access a vocabulary support tool; she accounted for half of vocabulary support requested by all participants in the Manipulable Graphics Condition.

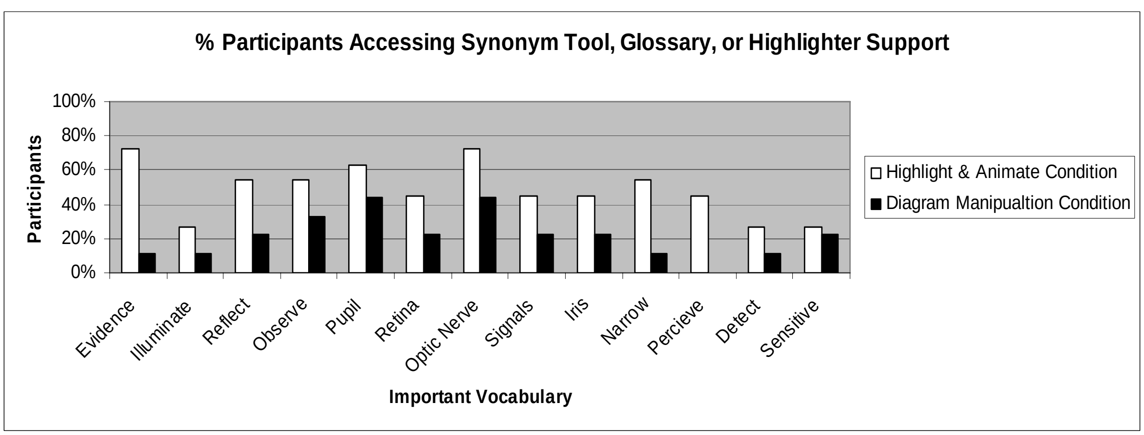

Figure 4.4
Participants use of vocabulary supports by condition.

Next, I examined readers' transcripts to discover how they interacted with the ideas of the text with respect to cognitive, lexical, and graphic demands with an eye to how their use of the affordances of the digital environment facilitated or constrained their efforts to meet the demands of the text.

Readers' Interactions with Ideas: Meeting the Conceptual, Lexical, and Graphic Demands

In the *analysis of ideas*, transcripts were carefully reviewed in search of patterns of readers' responses, by condition, to conceptual, lexical, and graphic demands of the text. The patterns that emerged and were selected for inclusion in this analysis were reader moves that (a) were necessary and/or likely to facilitate learning from graphic-rich science text, and (b) described and distinguished participants across conditions. Once patterns were identified, each reader's transcript was again reviewed and readers' interactions with the text were characterized in terms of those patterns.

Conceptual demands. The units of study for the analysis of readers' responses to conceptual demands were the best statements from the qualitative analysis of knowledge articulated (see Table 4.6). Recall that best statements were the propositional clusters that aligned with thirteen expert-identified important ideas from *How Do We See*. Readers' responses to the conceptual demands of the text were characterized as conceptually 'complete' or 'partial' with regard to whether or not they engaged in scientific practices when addressing the important ideas (see Fortus, et al., 2006). Conceptually complete statements were those that included an explanation of phenomena or statement of a scientific principle. They are identical to the 'complete' statements of the rating scale in Table 4.6. Conceptually partial statements described phenomena, but without explanation, or described a specific situation without stating the scientific concept that was represented by that example. These were the statements that met the criteria for 'adequate' in Table 4.6. See Appendix E for the rubrics specific to each important idea that guided evaluation of readers' responses as conceptually partial or complete.

Lexical demands. All of readers' verbal responses to the text, not just best statements, were used in this analysis. Readers' responses to the vocabulary of the text were satisfactory if the participant used the vocabulary of the text. Unsatisfactory responses did not use the vocabulary of the text and referred to important structures and functions nonverbally (e.g., gesture with cursor or hand) or verbally with oblique referents (e.g., 'goes like this,' 'that one,' 'over there') or vague, descriptive terms (e.g., 'the blue part' for 'iris'). Each page of *How Do We See* had several key words, which appeared in blue font and were linked to glossary, synonym, and/or highlighter tools. Readers' complete transcripts for each page were examined to see if they used each key word, even once, in their spontaneous or elicited responses to that page. Records of whether or not participants used key words were checked by a second person and discrepancies were resolved by recounting.

Graphic demands. All of readers' verbal and nonverbal responses to text were studied in this analysis. Readers' responses to the graphic were productive when the reader identified critical features of the graphic, investigated with a purpose and a plan, and interpreted the results of their investigation to produce accurate statements and explanations of scientific principles. Readers' interactions with the graphics were unproductive, even misleading, when they attended to peripheral, rather than critical, features of the graphic, investigated without a purpose and plan aligned with the important ideas of the page, and described the procedures and events specific to the page without looking for broader scientific principles. The complete transcripts of readers' responses to each page were reviewed for evidence of what readers identified as critical elements of the graphic, how they investigated the graphic, and what interpretation they assigned to the results of their investigation, as these actions were consistent, or inconsistent, with the important ideas of *How Do We See*.

In the next section, I provide evidence that readers' interactions with text were characterized by these patterns of responses to cognitive, lexical, and graphic demands, and that the Highlight & Animate and Manipulable Graphics groups could be distinguished by these patterns.

MEETING THE CONCEPTUAL CHALLENGES

Since conceptually complete and partial statements are the same as the complete and adequate statements of the analysis of knowledge articulated, we already know that readers in the Highlight & Animate Condition were more likely than those in the Manipulable Graphics Condition to meet the conceptual challenges by providing both a description of phenomena and a statement of scientific principle (see Figure 4.1). This pattern makes sense in light of what we know about the construction of informational text and what the analysis of affordances demonstrated about readers' use of the affordances of the Highlight & Animate and Manipulable Graphics Conditions. *How Do We See*, like other informational text, used graphics to efficiently depict the structure and function of phenomena. In addition, it offered the opportunity to manipulate the diagram in order to make aspects of the phenomena, which were not usually available to perception, more salient. The analysis of affordances showed that readers in the Manipulable Graphics Condition, who encountered (a) a large and challenging chunk of prose, (b) a diagram that could be manipulated, and (c) *Directions to Investigate* that led them toward the diagram, focused on the apparently more accessible diagram rather than the prose. The analysis of ideas showed that the knowledge they articulated frequently addressed what those graphics communicated: how things looked and what happened (a 'partial' description). So, readers in the Manipulable Graphics Condition spoke more of actions than of purposes for those actions; they spoke more of specific events than of scientific principles that explained the causes and consequences of those events.

How Do We See, as is typical of scientific writing, was constructed with prose that provided information to guide the interpretation of graphics, as well as to explain the general scientific principles and relationships demonstrated in specific examples in the graphics. The analysis of affordances showed that readers responded to the Highlight & Animate Feature by concurrently allocating attention to both the highlighted ideas in the prose and the animated representations of those ideas in the graphic. The analysis of ideas showed that readers in the Highlight & Animate Condition often articulated knowledge that provided evidence of the integration of information from both graphics and prose. Readers in the Highlight & Animate Condition included description of phenomena, to be found in large measure in graphics, and explanations of scientific principles, to be found mostly in the prose.

The landscape model of text comprehension (van den Broek and Kremer, 2000) provides a framework that is helpful for understanding how readers' focus on the diagram, in the Manipulable Graphics Condition, or on the highlighted prose and the animated graphic, in the Highlight & Animate Condition, guided their construction of qualitatively different representations of *How Do We See*. As discussed in Chapter 2, the quality of the mental representations that readers construct depends on several factors including: the readers' choices of information sources to which they allocate their attention, the strategic actions they take to ensure understanding, their standards for coherence, and the background knowledge and experiences they bring. The following examples contrast excerpts from the transcripts of readers in the Highlight & Animate Condition and readers in the Manipulable Graphics Condition. Note that when readers in both conditions used comparable strategies (e.g., paraphrasing the text, questioning), but different information sources, they produced qualitatively different representations of the text. It also seemed that readers' choice of information sources either facilitated or constrained the strategic actions available to them. Following these examples I address the issue of how differences in background knowledge affected the quality of mental representation that readers built of the experimental text.

Cognitive and metacognitive strategies. Participants in both conditions frequently used the strategy of reviewing the text that they had just read – a common move for readers of challenging informational text. Their actions included rereading or paraphrasing and describing the events in the animated graphic or noting the changes in the Manipulable Graphics. Participants in the Highlight & Animate Condition usually returned to the important/highlighted prose and associated, animated graphic each time they activated the Highlight & Animate Feature. Though they were not prompted to do so, they often re-activated the Highlight & Animate Feature several times. There is evidence that those in the Highlight & Animate Condition were particularly advantaged by revisiting the prose, which provided guidance in interpreting ideas in the graphic.

Each time readers returned to the prose, they were able to employ increasingly more sophisticated comprehension fostering activities. They gradually developed more complete interpretations of the information in the graphic, as enlightened by the prose, and of the ideas in the prose as illustrated in the graphic.

Mariah was a reader who moved from initial rereading to paraphrasing incorrectly, to describing correctly and connecting to her own experience, and finally to articulating the big idea, as her understanding evolved with each review of the text. Mariah's examples are drawn from page 2 of *How Do We See* (see Figure 4.5), which showed light striking objects on a table, and explained how light might be reflected from an object to our eyes so we could see it, or absorbed or blocked from reaching our eyes so we could not see it.

After reading the text once, Mariah re-activated the 1st Highlight & Animate symbol, noted changes in the graphic and quoted the prose correctly:

> **When I clicked on the first** [Highlight & Animate symbol]**, the picture changes, cause it said the light, the light, light reflect from the cover of a book reaches the per, the person's eye so he, he sees the book.**

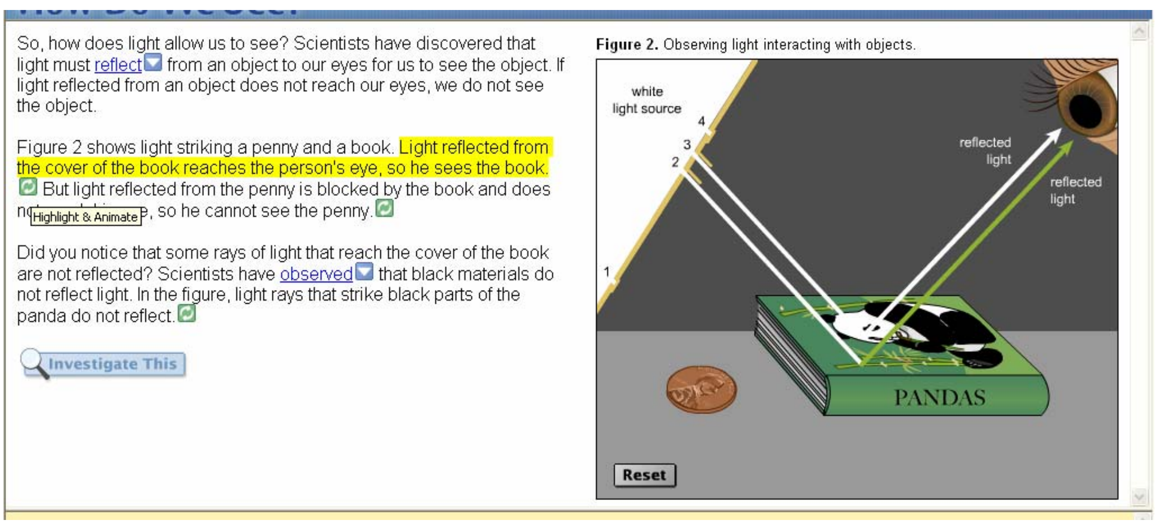

Figure 4.5
Page 2 of How Do We See in the Highlight & Animate Condition

Mariah spontaneously re-activated the 1st Highlight & Animate symbol again, ventured to <u>paraphrase</u> the highlighted prose, but *incorrectly* defined the path of light, and moved her cursor as though traveling in the *opposite* direction as she had read about:

> **So, the person's eye reflected on the book or on the panda up to the light source.**

Later, in the interview, she was asked what she learned. She re-activated the 1st Highlight & Animate symbol twice more, moved her cursor along the words, studied the text silently for some time, and then <u>described</u> correctly what she finally understood about the path of light.

> **The light, I think that the light from the, the light to the book to the eye reflected like that because um, the light came down on the book and it hit from the book and it shot up to the eye.**

To 'tell me how you figured that out,' she <u>reflected on her own thinking and connected the idea in the text to her own experience</u>:

> **In the text it said, 'light reflect from the cover…' I had to think about it.** *"The light reflected from the cover of the book reaches the person's eye."* **Okay.** "*Light reflected from the cover of the book reaches the person's eye so he says, so he sees the book."* **So that means… the light reflected from the cover of the book, so… the light shot all the way down to the book, would hit the… hit the book, and shot up. 'Cause you know… if you bounce a ball and… if it like hits and it comes back up? The light hit it and it came back up and came to the eye.**

There was abundant evidence that as Mariah repeatedly tacked back and forth between prose and graphic and came to understand what happened in the graphic (e.g., **The light hit it and it came back up and came to the eye**), she was also able to say how it happened (e.g., **When the light… hits a black surface it um, it does not reflect back up**) and why it was important (e.g., **so he, he sees the book; so the eye can't see the penny**). In other words, the knowledge that Mariah eventually articulated about this page was conceptually complete. Her experience was typical of other participants in the Highlight & Animate Condition, who all addressed at least one of the three important ideas on page 2 with a conceptually complete statement.

In contrast, only one-third of participants in the Manipulable Graphics Condition articulated knowledge of any of the three important ideas of page 2 in a manner that was complete. Alycia's experience was typical of readers in the Manipulable Graphics Condition. (See Figure 4.6 for the context in which Alycia was working.)

Alycia reviewed the ideas on page 2 by means of repeated interactions with the manipulable graphic. The purpose for her investigation it seemed was, appropriately enough, to see if light reflected from objects to the eye. She described her procedure as:

> **taking my time and looking closely and trying like figure out to see if it's going to actually beam to the eye or it's not.**

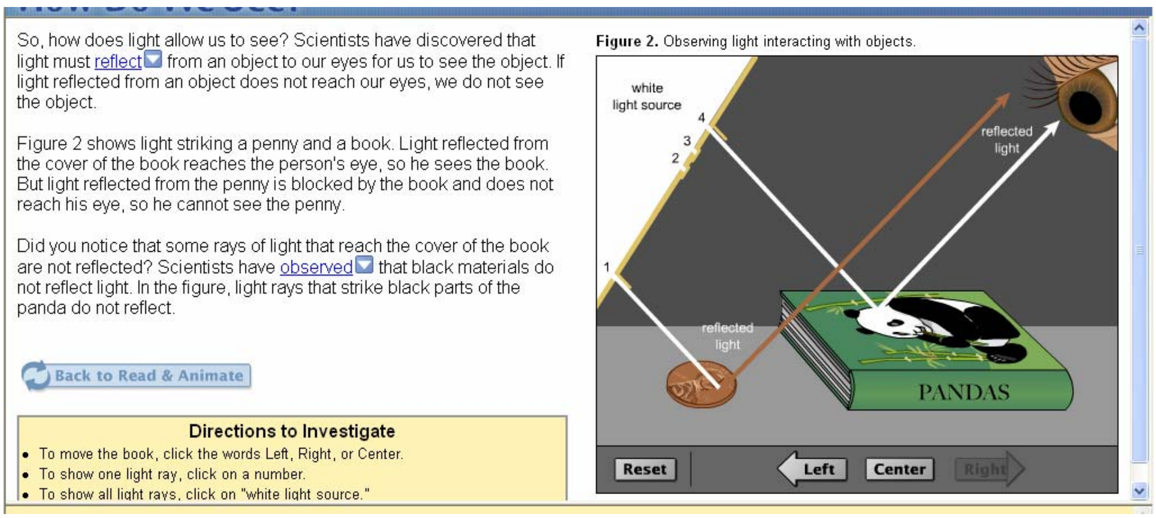

Figure 4.6
Page 2 of *How Do We See* in the Manipulable Graphics Condition

There was evidence that Alycia's multiple interactions with the graphic were insufficient to enable her to articulate knowledge in a way that met the conceptual demands of the important ideas of page 2. Alycia reviewed events in the graphic, describing them as they unfolded in response to her manipulation of the diagram. She described some actions of the graphic (see Figure 4.6) inaccurately as showing that light was NOT reflecting to the eye. When she was not satisfied with her interpretation, she labeled the graphic 'confusing' and proposed an alternative idea.

> **but this one's** (points to light from source 1 bouncing off penny and apparently going above the eye) **kind of like confusing cause… it's not**

> **reflecting or anything. So, you would probably think it would reflect ‘cause it looks like it’s like aiming for the eye, but it’s not. And this one** (points to arrow from 4 bouncing off book and hitting the eye) **kind of looks like it would beam off the eye, but it’s not.**

She continued to explore the diagram, trying to figure out why light rays that looked like they should reflect, did not. She never gained insights that would enable her to revise her mistaken descriptions of some of the events. There was no evidence that Alycia returned to the prose of page 2 at all. Alycia did bring her own knowledge to help her make sense of what she saw on page 2.

> **if the beam hit the book it would like shine back, like if you had a mirror and you had and the sun beaming down on the mirror it would bounce that way. Cause I… did that before and um the sun beamed to it, and then it beamed back that way.**

It was clear from Alycia’s explanation – about why some rays of light reflected from objects and others did not – that neither her investigation of the graphic nor her own knowledge were enough to enable her to articulate an important idea accurately and completely. Her explanation lacked any reference to the big ideas presented in the prose: we see an object when light is reflected from it; we do not see an object when it absorbs light or when another object blocks its reflected light. She said:

> **you don’t have the penny** (or the book) **in the right place to beam it off**

The contrasting examples of Mariah and Alycia are representative of the relatively stronger conceptual nature of knowledge articulated by participants in the Highlight & Animate Condition and the greater emphasis on procedural and descriptive knowledge by participants in the Manipulable Graphics Condition. This pattern is found across the experimental conditions for all pages of *How Do We See*, except one. Page 6 is worthy of particular attention, since it may be compared to the other pages of the text and inform the effective design of future digital reading environments and instruction in the optimal use of those environments.

The important idea on page 6 of *How Do We See* was that light is absorbed or reflected by materials in proportion to its depth of color. In the Manipulable Graphics Condition, two-thirds of participants articulated knowledge that reflected this important idea sufficiently accurately and completely.

> **…lighter colors reflect more than dark colors.**
>
> **…if you have the table black, then white doesn't reflect on it. If you have a table white, it reflects really good on your eyes and if you have it gray or light gray it reflects a little bit, or it reflects I guess a tiny bit.**
>
> **…if it's lighter it reflects and if it's like darker, anything like dark, but it's still kind of reflected. But like when it had all like all black, it didn't do it.**

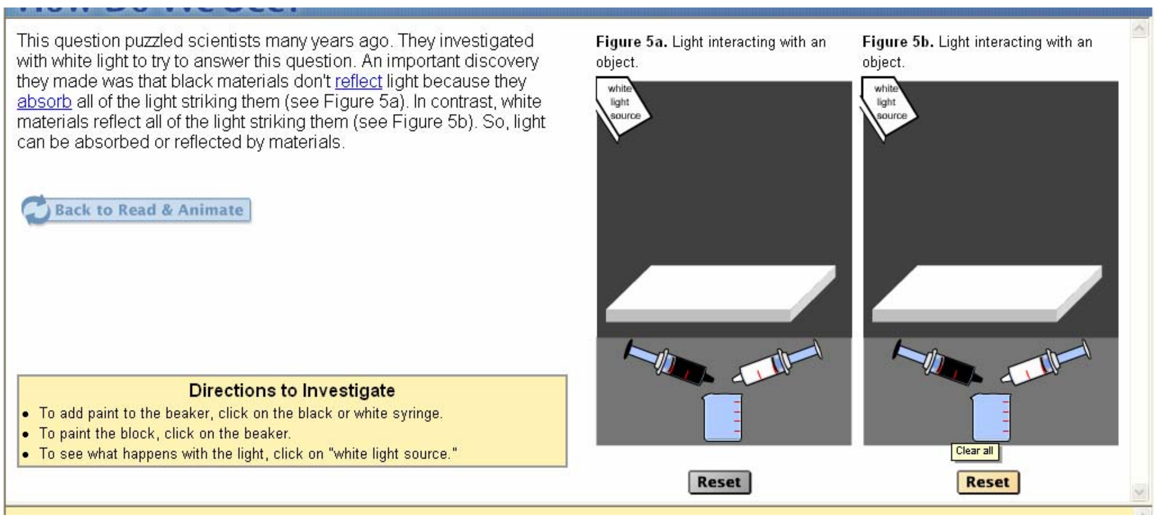

Figure 4.7
Page 6 of How Do We See in the Manipulable Graphics Condition

Readers in the Manipulable Graphics Condition were able to change the intensity of the color of the surfaces from which light reflected (see Figure 4.7). (See page 6 of *How Do We See* in Appendix A to see how surfaces may be changed from white to shades of gray to black.) When they activated a light source to make light strike the surface of a board, they saw how much or how little light reflected from it. It is my hypothesis that this investigation enabled participants to meet the conceptual demands of this page because of at least two important features. First, the reader changed the element of the graphic that mattered most – in this case it was the intensity of the color of the reflective surface that was important in inferring the important idea. Second, the directing code was explicit. Participants colored and then directed light at two surfaces whose side-by-side position made it clear that participants were to compare the results of their experiment. These features will be developed further in the upcoming discussion of how readers met the graphic demands of the experimental text.

So, there is evidence that readers' responses to the conceptual demands of *How Do We See* were shaped by their interactions with the affordances with their respective experimental conditions. However, there is also evidence that readers' production of conceptually complete or partial accurate best statements was mitigated by another factor – background knowledge.

Background knowledge. Those readers in the Highlight & Animate Condition who best met the conceptual demands of the text were those with the most incoming conceptual knowledge. Those who had little incoming knowledge of some important ideas were among those least able to articulate important ideas completely after engaging with the text in the Highlight & Animate Condition. Figure 4.8 shows this trend: .[12] This finding is consistent with the previously cited research noting the importance of readers' existing knowledge to support their construction of representations of text.

[12] Figures 4.8 and 4.9 were designed to show the *relative relationship* between overall amount of background knowledge and mean quality of best statements across participants within a condition. The values on the y axis may be used only to interpret the lower, darker line of data points on each graph that show participants incoming knowledge. The upper, lighter line of data points represents the quality of participants' best statements. While these data for quality of best statements are represented in accurate proportion to each other, values on the y axis are not applicable to these data.

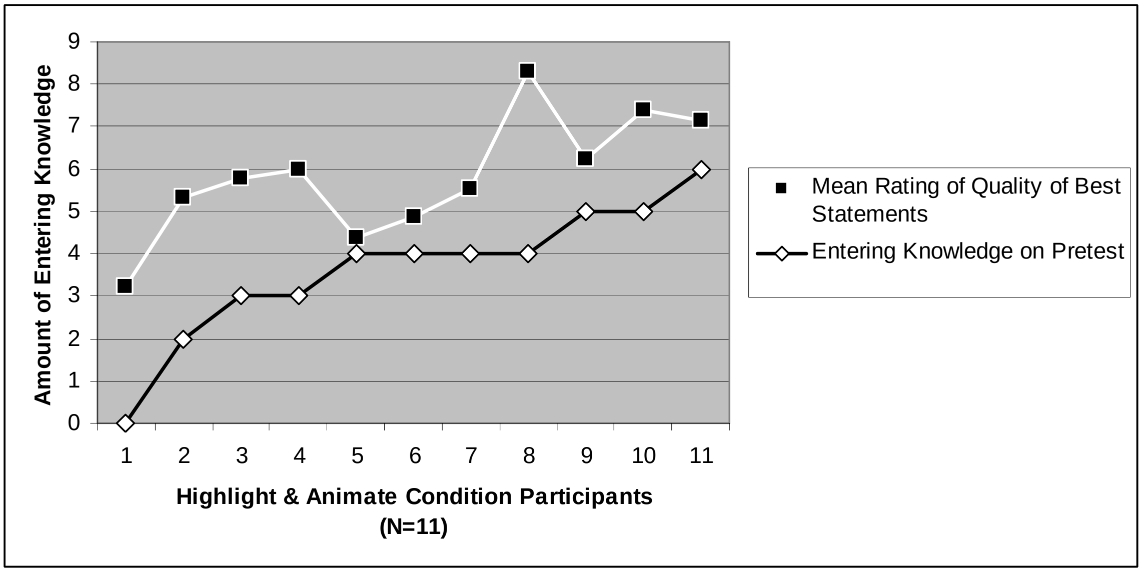

Figure 4.8
Relation between background knowledge and knowledge articulated:
Highlight & Animate Condition

The relationship between participants' prior knowledge and knowledge articulated after reading the experimental text in the Manipulable Graphics Condition was more surprising.

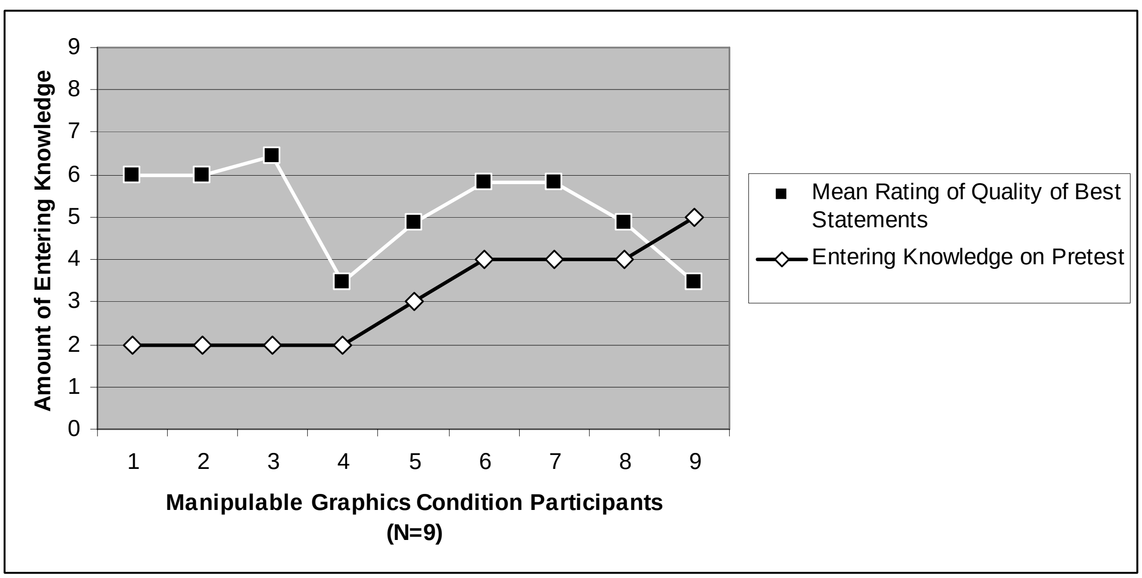

Figure 4.9
Relation between background knowledge and knowledge articulated:
Manipulable Graphics Condition

Several participants (Participants 1, 2, and 3 in Figure 4.9) who brought the least conceptual knowledge were among those most likely to articulate important ideas completely after interacting with the text in the Manipulable Graphics Condition. It seemed that manipulating the graphic in the Manipulable Graphics Condition offered them an introduction to previously unknown but important ideas and a means of interacting with those ideas. These low-prior-knowledge readers also deployed some strategies, described in the following paragraphs, which, in tandem with their attention to the graphics, enabled them to meet some of the conceptual challenges of *How Do We See*. One reader who entered the Manipulable Graphics Condition with the most conceptual knowledge about light and vision was not as likely as most of the low-prior-knowledge participants to articulate the important ideas of the text completely (Participant 9 in Figure 4.9). It seemed that the graphic manipulation of the Manipulable Graphics Condition did not necessarily prompt readers to express their existing knowledge or new knowledge completely, that is by describing not only what happened, but what was significant about it.

MEETING THE LEXICAL CHALLENGES

Readers met the lexical demands of *How Do We See* when they adopted the specialized language of the text, using it independently in their spontaneous responses to the text or in response to the interview questions. Key words, which appeared in blue font and were linked to glossary, synonym, and/or highlighter tools, constituted the specialized vocabulary of the text. Figure 4.10 shows the key words and the proportion of participants, by condition, who used each word in response to the experimental text. While participants in both conditions had access to the same prose with identical key words presented in the same way, participants in the Highlight & Animate Condition were, in general, twice as likely as those in the Manipulable Graphics Condition to independently use the vocabulary of the text. The following examples of participants' use of the vocabulary of *How Do We See* are taken from page 4, which describes the function of the iris and the pupil.

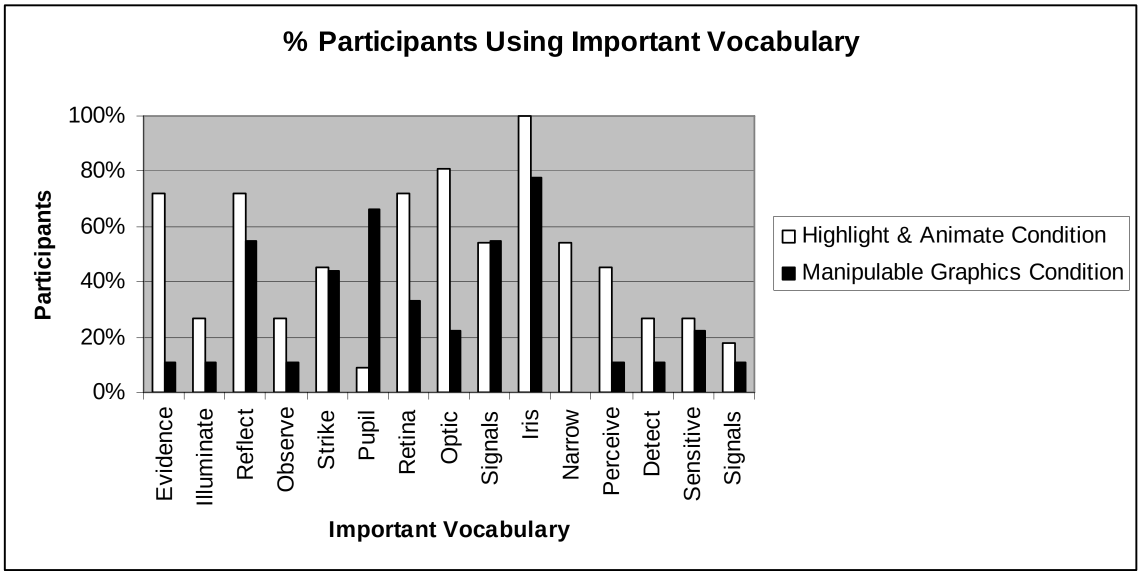

Figure 4.10
Participants' Independent Use of the Important Vocabulary of *How Do We See*: Evidence of Meeting the Lexical Challenges

Mike's frequent, correct use of 'iris' and 'pupil' was typical of the satisfactory way in which participants described what they learned from page 4 in the Highlight & Animate Condition (see Figure 4.11):

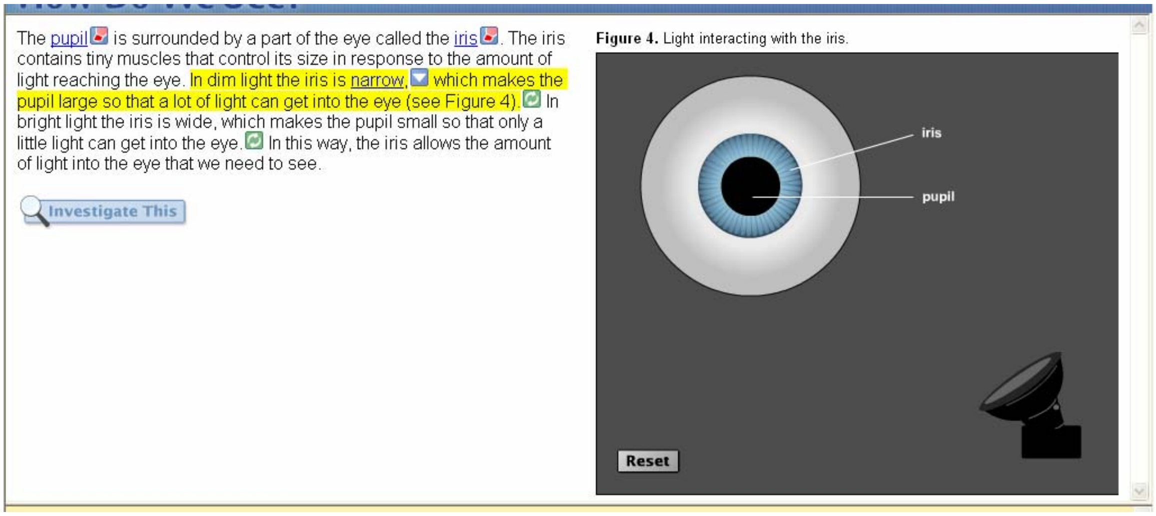

Figure 4.11
Page 4 of *How Do We See* in the Highlight & Animate Condition

Mike said:

> **And it shows that the <u>iris</u> is thinner and the <u>pupil</u>'s bigger…. the <u>pupil</u> is getting bigger as the light turns out. And it shows it when it's bright light, the <u>iris</u> is bigger and the <u>pupil</u> is smaller…. I learned that the <u>iris</u> controls the whole, controls the <u>pupil</u> and how big and how small it goes and how much light comes in.**

In place of the key vocabulary, participants in the Manipulable Graphics Condition sometimes used everyday words (e.g., 'the black part' for 'pupil'). More frequently, they substituted a pronoun (e.g., 'it,' 'that') for key vocabulary. Though participants in the Manipulable Graphics Condition often did not supply a verbal referent for the pronoun, they did intermittently supply a referent by means of a gesture with their cursor. While gestures were helpful, they were not always sufficiently consistent or precise enough to make the participants' meaning clear. Generally, then, the knowledge articulated by participants in the Manipulable Graphics Condition was lexically unsatisfactory.

Katie's account of what she learned from page 4 (see Figure 4.12) was typical of participants in the Manipulable Graphics Condition. Her description of the workings of the iris and pupil was remarkable for the complete absence of the words 'iris' or 'pupil.' She began with several references to 'it' (underlined), which could not be interpreted without verbal referents or accompanying gestures. It only became clear that hers was an accurate account of the function of the iris (an understanding that many participants did not acquire in the course of reading page 4) when, part way through the explanation, she began to point with her cursor and then used the synonym 'the black part' for 'pupil.'

> **Katie: When <u>it's</u> darker <u>it</u> turns bigger. My mom told me that. And when <u>it</u> gets really light, it's … It's not changing that** (pointed to pupil)**. It's changing that** (pointed to iris)**…. it's not this** (points to pupil) **that's getting bigger, it's that,** (points to iris) **that's changing… The black part is just stays the same.**

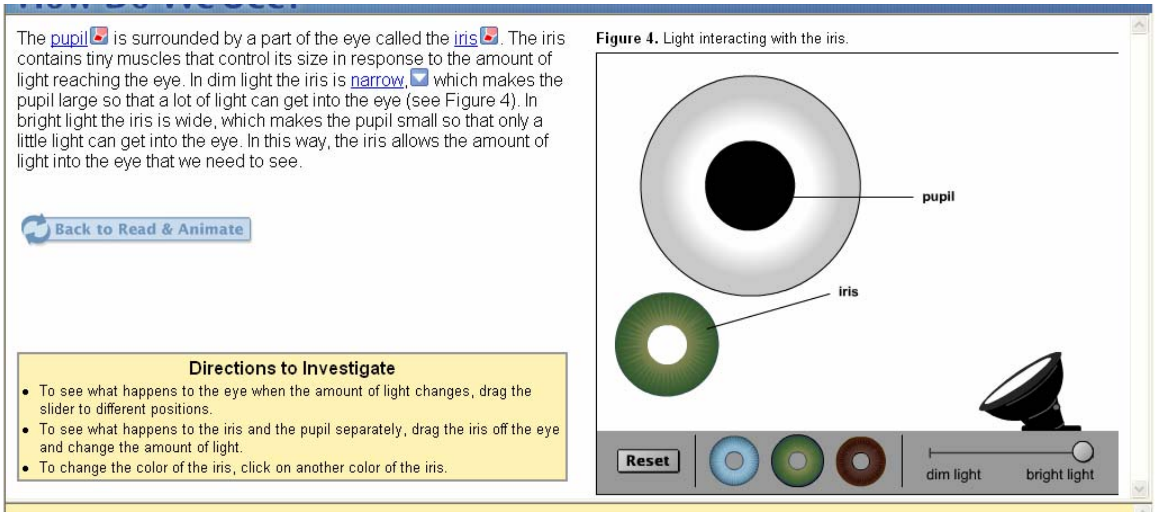

Figure 4.12
Page 4 of *How Do We See* in the Manipulable Graphics Condition

Since participants in each condition had comparable levels of entering vocabulary knowledge about light and vision, differences in the ways that they used the vocabulary of the text may be attributed to differences in their experiences with the affordances of the Highlight & Animate and Manipulable Graphics Conditions. In the previous description of readers' use of the Highlight & Animate Feature, evidence showed that participants in the Highlight & Animate Condition established a pattern of referring to words – the highlighted description and explanation provided by the prose – in coordination with their attention to animated aspects of figures. And, they often did so more than once as they re-activated a Highlight & Animate Feature. Also, recall that participants in the Highlight & Animate Condition accessed the vocabulary support tools frequently. Thus, readers in the Highlight & Animate Condition provided themselves with multiple exposures to key vocabulary in contexts that modeled what the words meant and how they should be used. In addition, readers gained opportunities to practice using key vocabulary when they quoted and paraphrased highlighted words as they described what they noticed or learned from the text. Readers in the Highlight & Animate Condition seemed to use the vocabulary of the text frequently because they had practice with them and developed an expectation that the words of the text were important.

In contrast, evidence from transcripts showed that participants in the Manipulable Graphics Condition had fewer 'built-in' opportunities to review the prose and study or use the key vocabulary it contained. For example, participants followed the *Directions to Investigate,* which focused exclusively on how to manipulate the diagram (e.g., 'To move the book, click on Left, Right, or Center'). The directions did not model or otherwise prompt a description of the ensuing action or an explanation of its effect. And, participants did not either create their own opportunities, or take advantage of means that were available to them, to study key words. For example, participants did not consistently attempt to describe their interaction with the diagram on their own. Rather, half of the time they investigated in silence, apparently without returning to connect the words and ideas of the prose to their manipulation of the diagram. Also, participants in the Manipulable Graphics Condition made minimal use of the vocabulary support tools, in comparison to participants in the Highlight & Animate Condition.

The Manipulable Graphics Condition had no specific opportunities for monitoring comprehension, which might lead participants to access vocabulary supports. That is, there were no points at which readers were required to interrupt their reading to review ideas as they did in the Highlight & Animate Condition. However, a number of the important words were printed at appropriate points on the figure. Readers in the Manipulable Graphics Condition seemed to use the vocabulary of the text minimally because they had few models of when and how to refer to it to describe the investigation of the graphic and/or enhance their communication and their thinking about their investigation. It is also possible that some participants did not see the need for specific vocabulary choices since the interviewer had shared the participants' perspective by observing the investigation.

MEETING THE GRAPHIC CHALLENGES

Participants grappled with the graphic challenges of *How Do We See* as they *identified, investigated, and interpreted* information presented in the graphics. Each of these activities, in which readers interacted with the text, will be described briefly, next. Then, some of the sources of variation by condition in readers' interactions with the graphics of

How Do We See will be identified. Finally, participants' interactions with the graphics on some of the pages of the text will be presented to illustrate how readers identified, investigated, and interpreted the graphics in response to the affordances of the Highlight & Animate and Manipulable Graphics Conditions. Note that in this section the reader will be referred to the Appendix as the most expedient way to gain access to multiple examples of graphics from pages from the experimental text.

Readers' interactions with the graphics. Readers *identified* the real-world referents for the situations, objects, and phenomena depicted in the largely iconic diagrams of the experimental text (e.g., a cave, sources of light, concentric rings of white, black and blue that represented the pupil and the iris in the eyeball). In other words, readers interpreted the depicting codes (Weidenmann, 1994). Readers also had to figure out what were the most important aspects of the graphic (e.g., color, relative size or position, function, trajectory of movement). That is, they had to interpret the directing codes (Weidenmann, 1994). Readers depended in large measure on animation – movement or change that made aspects of the graphic salient – to identify critical aspects of the graphic.

Readers focused on the most salient aspects of the graphic when they *investigated*. They produced different perspectives, examples, and effects by animating (in the Highlight & Animate Condition) and manipulating (in the Manipulable Graphics Condition) the figures (e.g., making a cave dark, making light strike different objects, or striking the same object at different points). Aspects of the investigations that were of particular interest in this analysis were:

- the organization of reader moves in their investigation (e.g., systematically holding one variable constant while changing another, thoroughly testing every available option, or working through the ideas of the text in sequence), and
- the purposes that directed the reader to engage in cognitive activities that would enable them to discover the phenomena and relationships among phenomena represented in the graphic. (e.g., making a comparison, discovering a pattern, or discerning the conditions under which something happened).

Readers *interpreted* the graphic as they learned, or built mental models from the representations of the phenomena they animated and manipulated in their investigations. Some of their interpretations (e.g., cause-effect explanations of events, generalizations of specific examples to statements of scientific principle, or functional relationships discovered between phenomena) indicated that interactions with the graphics facilitated meeting the conceptual challenges of *How Do We See.* Other interpretations indicated that readers were attending to the procedural and descriptive, rather than conceptual, aspects of the graphics. For example, readers described actions, changes in appearance, or the steps taken to animate or manipulate the figure.[13]

Sources of variation in readers' interactions with graphics. Readers' interactions with the graphics varied in response to affordances, unique to each condition, which were discussed earlier: the design of the graphics, the opportunities for interacting with them, the nature of the guiding instructions, and the subsequent balance or imbalance between attention to prose and graphics. Recall that the design of the graphic was somewhat different for the same page across conditions. Though the conceptual target usually remained the same, the visual representation varied in some ways. Page-by-page comparisons of the differences in graphic design for pages across experimental conditions are provided in Appendix A.

The words that guided readers' investigations varied by condition. Participants in the Highlight & Animate Condition usually interpreted the graphic with guidance from the highlighted sentences that accompanied animation of the graphic. The highlighted prose included procedural, descriptive, and conceptual information. It explicitly stated what happened, why, and what relationships could be found between examples in the animated graphic and important, big ideas of the text. Readers provided evidence of the influence of the highlighted prose when they articulated knowledge about phenomena depicted in the graphic by using quotes, paraphrases, technical vocabulary, descriptions of processes, and explanations of relationships that were only available in the highlighted prose. Also,

[13] In the earlier, broader analysis of how readers met the conceptual challenges of the experimental text, only readers' accurate, best statements were considered. In this analysis of how readers interacted with the graphics, all of readers' verbal responses and nonverbal interactions with the text were studied.

they reread, toggled between prose and graphic with words and gestures, and credited both the highlighted prose and the graphic when asked how they figured things out.

Though participants in the Manipulable Graphics Condition had the same prose available, it was not broken into segments with important ideas highlighted. There is scant evidence that readers returned to the prose. Rather, the words that guided their work with the graphic were the *Directions to Investigate*. The directions were procedural in nature. They told the reader to perform actions that, in turn, produced a change in the graphic. The directions did not explicitly link graphic examples to important ideas. The reader was left to discover important relationships. Readers showed their attention to these directions when they carried out procedures as directed, described those procedures, and articulated knowledge that focused on the aspects of the graphic that they were told to manipulate – whether these were the most important aspects of the graphic or not. Readers credited their learning to their actions on the figures.

As a result of these differences in guidance, as well as differences in the construction of graphics, by condition, readers often interpreted the same graphic somewhat differently across conditions, for some pages of the text. The final pages of this chapter present several examples of readers' interactions with the graphics of *How Do We See*, which varied with the affordances of their conditions.

Identifying elements of the graphics. Participants in the Highlight & Animate Condition usually accurately identified the depicting codes of the graphics. Recall that participants in the Highlight & Animate Condition consistently used the important vocabulary of the text. With the use of these words participants accurately labeled symbols that depicted familiar (e.g., penny, book) and unfamiliar (e.g., retina, optic nerve) objects as well as abstractions (e.g., light, colors of light) represented by the iconic graphics. Participants' identification of symbols that depicted familiar items in the graphic was probably a product of good design of symbols. Written labels that appeared on graphics may have supported participants to identify unfamiliar or abstract symbols. When readers used the appropriate labels for symbols in sentences that they formulated –

rather than paraphrased from the prose or labels within the graphic – this constituted evidence that readers were identifying the elements of the graphic. It was difficult to know just how well participants in the Manipulable Graphics Condition identified the symbols in the graphics, since, as described earlier, they were less consistent than participants in the Highlight & Animate Condition in their use of the vocabulary of the text.

Readers in the Manipulable Graphics Condition had mixed success in determining which elements of the graphic, particularly dynamic elements (e.g., reflection, absorption), should be salient. Readers focused on elements of the graphic that they could manipulate. There were several reasons that this was not a fail-safe approach to identifying the critical elements of the graphic: 1) often more than one aspect of the graphic could be moved, 2) not everything that could be changed was (equally) important, and 3) sometimes what was important was something that did not seem to change. Readers in the Highlight & Animate Condition frequently referred to the highlighted prose that accompanied the animation. With this guidance they usually identified aspects of the graphic that were central to the important idea(s) represented in that graphic. Some readers in the Manipulable Graphics Condition, who did not have the highlighted prose to steer them to the important aspect of the graphic, on a number of occasions, attended to aspects of the graphic that were peripheral to the important idea. Or, they identified one important aspect of the graphic but missed other crucial elements. Different opportunities across conditions for identifying salient aspects of the graphic can be seen in this example.

Page 1 of *How Do We See* (see Appendix A) showed a person using a headlamp to explore a cave. The important idea was: we need light to see. In the Highlight & Animate Condition, activating the Highlight & Animate symbol produced a single event – turned out the lamp – and stated how to interpret that event. The highlighted prose told readers, 'when the light is turned off, a person in the cave cannot even see her own hand in front of her eyes.' Participants in the Highlight & Animate Condition, who saw the cave become completely dark as this sentence was highlighted, consistently addressed the critical aspects of the graphic by noting the darkness created when the light went off, the fact that they could not see anything on the screen/in the cave, and that we, or the caver, need light to see:

> **There's no picture... the screen turned black.**
>
> **It shows it all dark… she can't see cause of the lights turned off.**
>
> **One of the things you can learn on this page is that you need light to see.**

In contrast, participants in the Manipulable Graphics Condition changed the amount of light in increments, producing a series of events. (The directions stated: 'To change the beam width of the caver's headlamp, drag the headlamp slider.') A number of readers in the Manipulable Graphics Condition interpreted the graphic in ways that were central to the important idea: we need light to see. However, several readers in the Manipulable Graphics Condition attended to other aspects of the graphic, which were made salient by the gradually diminishing light produced by the slider, but were peripheral to the important idea. They described the process of operating the slider to produce more or less light and the optical effects created by different amounts of light on the walls of the cave:

> **It kind of looked like it was something different whenever you changed it** (moved the slider)**... things like this** (lighted area) **can like trick your eyes ... but you got to look carefully… it kind of looked like a bat or something, but it really wasn't anything.**
>
> **It looks like the branches with the leaves are down here… and it looks like there's grass and just haystacks down here… and then… clouds up there.**
>
> **It depends which way you want to move the thing to either get wider or darker. This one is getting small and it's getting darker.**

In summary, then, readers in the Highlight & Animate Condition consistently spoke of aspects of the graphics that were central to the important ideas, since these relationships were implicit in the scripted sequence of animated graphic events activated by the Highlight & Animate Features and explicitly stated in the highlighted prose, which they might review several times. (Note that in a few situations readers in the Highlight & Animate Condition produced statements that were very close paraphrases or verbatim restatements of the highlighted prose. We cannot be sure, in these few situations, how well the readers understood the relationships of which they spoke.) Participants in the

Manipulable Graphics Condition also spoke of the graphic in ways that were central to the important ideas. When they did so, it seemed certain that they had gleaned the directing codes from the graphic and, to a lesser extent, from the *'Directions to Investigate,'* since they had not reviewed the prose that clarified how aspects of the graphic illustrated the important ideas. At other times, readers in the Manipulable Graphics Condition spoke of aspects of the graphic that were (perhaps inadvertently) made salient to them by the animation, but were peripheral to the important ideas of the text.

Investigating and interpreting the graphic in the Highlight & Animate Condition. The Highlight & Animate Condition generally assured organized, purposeful investigations of graphics, which enabled participants to articulate an accurate interpretation of many of the important ideas of the text. The purpose of each inquiry, that is, the claims to be investigated, were implicit in the graphic examples of phenomena and explicitly stated in the accompanying highlighted prose. As readers activated the Highlight & Animate Features in sequence, examples of the phenomena to be investigated were animated in steps that were carefully scripted to build an argument or show contrasts between important features. The simultaneously highlighted prose directed readers to identify the most important elements of the graphics, clarified the behavior to be observed in the investigation, and, usually, specifically stated what relationship was to be found. In response to the simultaneous presentation of information in graphics and prose, participants articulated knowledge that integrated verbal and visual representations.

Readers' interactions with pages 3 of the experimental text (see Appendix) show some of the strengths of the Highlight & Animate Condition as an environment in which readers might learn from an investigation of the graphics. Page three describes how light interacts with structures of the eye to enable us to see. Readers in the Highlight & Animate Condition used the Highlight & Animate Feature to efficiently and thoroughly investigate the graphic representation of a body system that is normally not observable. They activated each of three Highlight & Animate symbols, in sequence, and were directed to points along the path of light as it traveled from its source to the pupil, then through the pupil to interact with other structures of the eye on its way to communicate a message to the brain. The knowledge that readers articulated made it clear that this investigation prompted readers to construct a mental representation of the path of light from pupil to brain that was an accurate interpretation of the graphic. Readers summarized the big ideas, asked questions, monitored their own understanding, and made connections to their own experience as they articulated procedural, descriptive, and conceptual knowledge:

> **I never knew that it** (the light) **will hit the back of your eye and go through, go around the optic nerve. It showed me what the light does inside your eye and outside.**
>
> **Your brain tells you what you're seeing. Did you know that our eyes are connected to our brain?**
>
> **So, if I wanted to see, so, if I could see that mirror and if I wanted to, the light source would go in my eye, hit the retina, and go to the optic nerve that leads to my brain.**

Participants who conducted the most thorough investigations and produced the richest, most nuanced interpretations of the graphic were those who spontaneously self-explained the information presented via the animated graphic, with the aid of the prose, as they activated each Highlight & Animate Feature. Then, after reading the text once, they reviewed each of the Highlight & Animate 'touchstones' on their own and as they responded to the interview questions. By reviewing the graphic and prose several times, readers of page three arrived at gradually more accurate or complete interpretations of the structure and function of the eye. Jillian's experience was typical of some readers in the Highlight & Animate Condition. As she read each chunk of text she commented on each animated graphic and highlighted prose:

> Text: *Figure 3 also shows that light entering the eyeball strikes the retina, which is connected to the optic nerve.* [Highlight & Animate symbol]
>
> **Jillian: Okay, the retina's right here** (points) **and the optic nerve is right there** (points). **I wonder what's that yellow stuff coming in… I think that's the optic nerve. Let's see, it goes through there** (traces path of light to retina) **and I think it's supposed to go through there** (optic nerve) **I think.**

After reading the text, she spontaneously reviewed the important aspects of the graphic signaled by the Highlight & Animate symbols:

> **Jillian: Oh now I'll investigate this. There's many different things… that was important. That there** (re-activates 1st Highlight & Animate symbol)**, it shows us where the light went in like two places.**
>
> **So…** (re-activates 2nd Highlight & Animate symbol) **these two** (rays of light) **go into here** (follows light rays from source to entry point at pupil) **and goes up to there** (follows path of light rays to retina)**.**
>
> **Then** (re-activates 3rd Highlight & Animate symbol) **it goes around** (follows path of light around edge of retina) **and… it goes in through there and tells what we see, our brain does.**
>
> **It showed me where the um, the lights go… It shows… what the…. octive artery looks, nerve looks like and… it shows where all the parts are, where it goes to.**

The last page of *How Do We See* provided an opportunity to see that the practices readers had developed as they investigated and interpreted the graphic and aligned prose with the Highlight & Animate Feature served them even when graphics were not completely aligned with the prose and even when they did not have a Highlight & Animate Feature to direct them. The prose of page 8 (see Appendix A) describes how light interacts with structures of the eye to enable us to detect over a million different colors. Designers chose to emphasize the great variety of colors using a color wheel graphic, rather than provide a diagram of the structures of the eye as on page 3. Also, designers did not insert a Highlight & Animate Feature to link prose and graphic. Even though they had not seen the structures of the eye animated in the graphic, nor seen prose aligned with the color wheel graphic the majority (67%) of readers in the Highlight & Animate Condition described both the function of the structures of the eye and the great number of colors that they enable us to see, in their responses to page 8, thus persisting in their established pattern of calling upon prose to supplement graphic information.

> **Our retina helps us detect different colors cause it has cones in it. That helps us detect different colors of what we see.**
>
> **Yeah, the optic nerve, the retina, and the pupil, and the, and the iris. All those work together to make you see, make you see all the colors in the world, every single color**
>
> **It's not really helpful because they don't have… a highlight where it's important. I guess something's important in there… we can see like different colors… cause our eyes, our eyes and our brain**

detected the colors... So, it brings this thing up from our head to our eyes so we know what we're seeing.

There were limitations in the extent to which the prose of the Highlight & Animate Condition supported learning from an investigation of the graphics. These limitations were apparent in at least two circumstances. First, the Highlight & Animate Feature was of limited assistance when the prose presented information that was neither consistent with readers' own knowledge, nor made salient by the graphic. On page four (see Appendix A), an idea stated in the prose (i.e., the iris changes size in response to light) was in direct conflict with many readers' own conception, revealed in the pre-tests (i.e., the pupil changes size in response to light). Also, which structure was changing size was not clear from the graphic in which the adjacent iris and pupil changed simultaneously. Readers were not persuaded by the prose or the graphic. Thus, only 27% of readers in the Highlight & Animate Condition correctly articulated an understanding of the role of the iris:

I learned that the iris controls the whole, controls the pupil and how big and how small it goes and how much light comes in.

Rather, most readers spoke of the pupil in a manner consistent with their own ideas.

When there's no light the um, the pupil gets bigger. But when there's lot, tons of light it gets smaller.

Second, the Highlight & Animate Feature provided insufficient support for investigating and interpreting the graphic when the principle to be learned was neither explicitly stated nor highlighted to provide guidance and, again, not made salient by the design of the graphic. Page seven states that "when white light hits a colored object, the color we see is the color from white light that is reflected by that object to our eyes, while all the other colors of white light are absorbed." This sentence, which states the important principle, was not highlighted. The graphic showed one example in which light struck a green object; the highlighted sentence described this event. Only 36 % of readers went beyond what was explicitly highlighted and animated to articulate the important idea.

For example, if you had a purple table, which I don't know why it would be purple… and then from the light, in the prism or

> **something…** (traces the purple light) **all the colors would come down, but that one color in that rainbow, which was that same color that was the object, it would come up back into your eye.**

Most readers articulated knowledge that interpreted this graphic with respect to the specific example.

> **The light that interacts with the green light can reflect off and bounce to see, so you can see.**

In summary, readers in the Highlight & Animate Condition were provided with a scripted investigation consisting of a sequence of 1, 2, or 3 animated graphic events designed to illustrate an important idea by means of examples or contrasts. Readers' only choice with respect to investigating the graphic – to re-activate the Highlight & Animate Feature to replay one or more of the animated graphics – provided opportunities for readers to monitor and improve their interpretation of the graphic by repeatedly checking their emerging understanding against the information in the highlighted prose. The guidance of the highlighted prose supported readers to use the animated graphics to accomplish the purposes recommended by Park and Hopkins (1993): to guide their attention to important points, interpret structural and functional relationships, make abstract ideas more concrete, and form mental images. Readers in the Highlight & Animate Condition frequently interpreted the graphic at multiple levels – descriptive, procedural, and conceptual – to the extent that they were guided by the aligned/highlighted prose to do so. However, the Highlight & Animate Condition failed to support readers to interpret the graphics of the experimental text where the prose to guide interpretation, or the design of the graphic to represent important ideas, were inadequately aligned with each other and/or the conceptual demands of the text.

Investigating and interpreting the Graphic in the Manipulable Graphics Condition. The Manipulable Graphics Condition offered unique opportunities for investigating and interpreting the graphic. Designers were cognizant of the fact that readers who held partial or naïve conceptions about scientific phenomena were unlikely to find written accounts of substantive scientific knowledge, which were incompatible with their own common sense explanations, to be convincing. So, in the Manipulable Graphics

Condition, designers created opportunities for readers to confront what designers predicted would be the readers' own naïve and incomplete conceptions in their investigations of the graphics. Page 4 of the experimental text in the Manipulable Graphics Condition offered one such opportunity.

Pre-testing showed that most participants came to the study with the conception that the pupil got bigger in dim light and smaller in bright light. We know also that few fifth graders realize that it is the iris that changes size in response to light and, thus, regulates how much light gets in the eye through the pupil. In the Manipulable Graphics Condition, on page four, readers could confront these conceptions (see Appendix A). They were able to drag the iris off the pupil. Then, when they changed the amount of light directed toward the eye, they could see the pupil remained the same size opening in the eye, while the iris changed size in response to changes in the amount of light. In response to their investigations, two thirds of participants in the Manipulable Graphics Condition noted that the iris – not the pupil – changed size in response to light. Their exclamations of surprise further confirmed that the knowledge they articulated was a new discovery.

> **The iris gets bigger when the light goes across it. And when the light comes back it gets smaller.**
>
> **Actually the color parts changes not the, not the black part.**
>
> **It's not this** (points to pupil) **that's getting bigger, it's that,** (points to iris) **that's changing; the black part just stays the same**

There were limits, however, to what readers learned by confronting their conceptions in this investigation of the graphic. Even though most participants in the Manipulable Graphics Condition were able to describe the procedure – how the iris and pupil worked when viewed separately – none described the functional relationship between them: that when the iris changed size, it regulated the amount of light that entered the eye through the pupil. How was it that participants in the Manipulable Graphics Condition learned *what* the iris did, but not *why* it did so? How was it that some participants in the Highlight & Animate Condition, whose investigation did not even show the iris and pupil working separately, could describe the functional relationship between the iris and the pupil? The answer to these questions lies in the design of the graphic and the nature of the guidance.

That the iris controlled the size of the pupil was not something that could be portrayed well graphically. Rather, it was complementary information supplied by the prose. Those in the Manipulable Graphics Condition, who were not supported to coordinate images in the animated graphic with the complementary explanation in the prose, interpreted the graphic in terms of what happened, but not why it happened. The *'Directions to Investigate'* guided the reader to investigate 'to see what happened', but did not suggest that readers use data from the investigation to hypothesize about why.

There was, perhaps, another reason why some readers in the Manipulable Graphics Condition did not arrive at the correct functional relationship of the iris and pupil. They were busy investigating the relationship of the change in size of the pupil to the color of the iris, rather than the size of the iris. Again, this can be explained as a product of the design of the graphic as well as the nature of the guidance to investigate the graphic. In an attempt to heighten interest by customizing the graphic, designers created an opportunity for participants to change the color of the iris. The *Directions to Investigate* stated, 'to change the color of the iris, click on another color of the iris.' All but two of the participants followed this directive. Readers, logically enough, assumed that what they were directed to change was important (it was not) and designed their investigations accordingly. They investigated the graphic by analyzing changes in the size of structures of the eye with respect to the color of the pupil. Thus, they expended precious resources on an investigation of a very peripheral issue.

The emphasis on learning from graphics and directions without integrating information from prose, which characterized participants in the Manipulable Graphics Condition, proved to be an asset on at least one occasion that required that readers' thinking not be constrained by the information available in the prose. On page 6 of *How Do We See*, participants in the Manipulable Graphics Condition had an opportunity to extend their partial conception by means of an investigation of the graphics (see Appendix A). A number of readers noted that they already knew the principle stated on page 6: black materials absorb light and white materials reflect light. Participants in the Manipulable Graphics Condition engaged in an investigation to extend this knowledge. They used black and white paint to color blocks black, white, and shades of gray. Then they directed light at the blocks to see how much light would reflect from the surfaces. Two-thirds of participants responded to this investigation by correctly inferring that light was reflected from an object in proportion to the depth of color of the object. So, in their interpretation of the investigation of the graphics, participants in the Manipulable Graphics Condition were not bound by the simpler principle, stated in the prose that reflected their own existing understanding. Through their investigation of the graphic alone, they were able to discover a previously unknown law governing the reflection of light.

> **Light and dark colors can reflect… just not plain black… but lighter colors reflect more than dark colors.**
>
> **If it's really dark it absorbs the light and makes the board really warms and if it's really light, it reflects off… even though if it's kind a darker gray than the lightest gray, it still reflects.**
>
> **If it's lighter it reflects and if it's like darker… it's still kind of reflected. But like when it had all like all black, it didn't do it. So if I like had ah white, see it does it, but like once it gets really dark, fully, fully dark, it won't do it.**

The design of the graphic on page 6 of the Manipulable Graphics Condition probably contributed to the efficacy of the participants' investigation of this page. The design was economical in several ways. It allowed the reader to change only one important feature – the color of the block. Readers could correctly infer that the consequences of their action – changes in the amount of light reflected from the block – were caused by their action. Also, the graphic offered two, side-by-side opportunities to change the important feature. Implicit in the side-by-side position of the figures was direction to the readers to create contrasting conditions – blocks of different colors – and compare what happened to each one when struck by light. These were directions that were not provided by the *Directions to Investigate*. In other words, this graphic made the directing codes for this page explicit.

In summary, in the Manipulable Graphics Condition, participants designed their own investigations of ideas represented in the graphics, within a range of possible moves. The '*Directions to Investigate'* alerted the reader as to how the graphic could be manipulated, but did not suggest a purpose (e.g., a claim to be tested) or a method (e.g., an efficacious structure) for the investigation. When readers conducted a thorough, organized investigation focused on aspects of the graphic that were central to the important ideas, they were likely to discover and articulate an accurate interpretation of the graphic. These interpretations more often focused on what happened – the procedural and descriptive aspects of the graphic – than why it happened – the conceptual aspect. The Manipulable Graphics Condition also offered readers the opportunity to build enduring scientific knowledge by confronting their own common-sense understandings.

Paradoxically, while readers had opportunities to build deep knowledge, they also had opportunities to deviate from central aspects of the important ideas. The difficulty developed in this way: if readers were to learn from their investigations, they had to structure well-organized inquiries that focused on aspects of the graphic that were central to the important ideas. Readers had a tendency to assume that all aspects of the graphic over which they had control were important; actually, some were important, some were not. Without prompting to review the relevant prose, with only procedural instructions of the *Directions to Investigate* as a guide, readers sometimes focused on salient but peripheral aspects of the graphic. Or, readers manipulated central aspects of the graphic, but in a way that was not sufficiently organized to enable the reader discover the relationship between phenomena depicted in the graphics and important ideas.

To conclude this chapter, fine-grained analysis of knowledge articulated, as revealed in reader transcripts, provided evidence that condition mattered. Working in either the Highlight & Animate or the Manipulable Graphics learning environments produced distinct differences by condition in meeting the conceptual, linguistic, and graphic challenges of the text. The affordances available in *either* the Highlight & Animate Condition *or* the Manipulable Graphics Condition provided different opportunities to interact with the text. Consequently, it is my claim that the readers' interpretation of the text and the manner in which they expressed their understandings were different by condition. Further, while both the Highlight & Animate and Manipulable Graphics Conditions successfully supported readers in specific ways, neither condition was sufficient to enable most readers to meet all of the conceptual, linguistic, and graphic challenges of *How Do We See*. In order to design environments and individualize instruction that can enable all readers to meet these challenges it is necessary to understand the role that individual differences played in shaping readers' interactions with the digital environments of their respective conditions. In the following chapter I present the cases of four participants in this research who responded quite differently, in both predictable and unpredictable ways, to the unique affordances of their experimental conditions.

CHAPTER FIVE: CASE STUDIES

Variations in Individual Readers' Interactions with the Experimental Text

The purpose of this chapter is to show, by means of case studies, some of the variation to be found within the experimental conditions in (1) participants' use of the affordances of the Highlight & Animate Feature or the Manipulable Graphics and (2) their understanding of the ideas of *How Do We See*. In Chapter Four, I looked across experimental groups to identify trends in participants' interactions with the affordances and the ideas of the experimental text. However, in that chapter, I also introduced evidence of variation in readers' experiences within conditions. The evidence included data from outcome measures of participants' knowledge about the topic of the experimental text. In terms of *knowledge articulated* (see Appendix F), participants in the Highlight & Animate Condition produced as few as 1, and as many as 11, best statements of the highest quality, or 'complete.' Those in the Manipulable Graphics Condition produced as few as 0 and as many as 6 complete best statements. In terms of *knowledge gained* (see Table 4.3), the pre-post change on the test of conceptual knowledge ranged from -2 to +5 points in the Highlight & Animate Condition and 0 to +5 points in the Manipulable Graphics Condition. Such wide, within-group variation in participants' command of the ideas presented in *How Do We See* suggested that participants may have interacted with the same digital environment in quite different ways. Studying those interactions may provide insight for customizing the design of electronic environments to support diverse readers' learning from text.

This chapter offers close-up views of four participants – one from each condition who was characterized as *'more knowledgeable'* and another from each condition, who was *'less knowledgeable.'* The featured participants were selected for inclusion in this chapter on the basis of the knowledge they articulated. Recall that in the analysis of knowledge articulated set forth in Chapter 4, participants' best statements, or propositional clusters that aligned with important ideas of the text, were rated on a 4-point scale.[14] The more knowledgeable participants (see Figure 5.1) consistently articulated their knowledge of the important ideas of the experimental text in a manner that achieved the highest rating, 'complete.' The less knowledgeable participants (see Figure 5.1) seldom identified the important ideas completely, or even adequately. As can be seen from Figure 5.1, case study subjects were chosen from the extremes of the continuum of knowledge articulated. Accounts of how these participants interacted with the experimental text in their respective conditions provide contrasting examples of highly productive, and minimally successful, experiences in building knowledge of the topic of *How Do We See*.

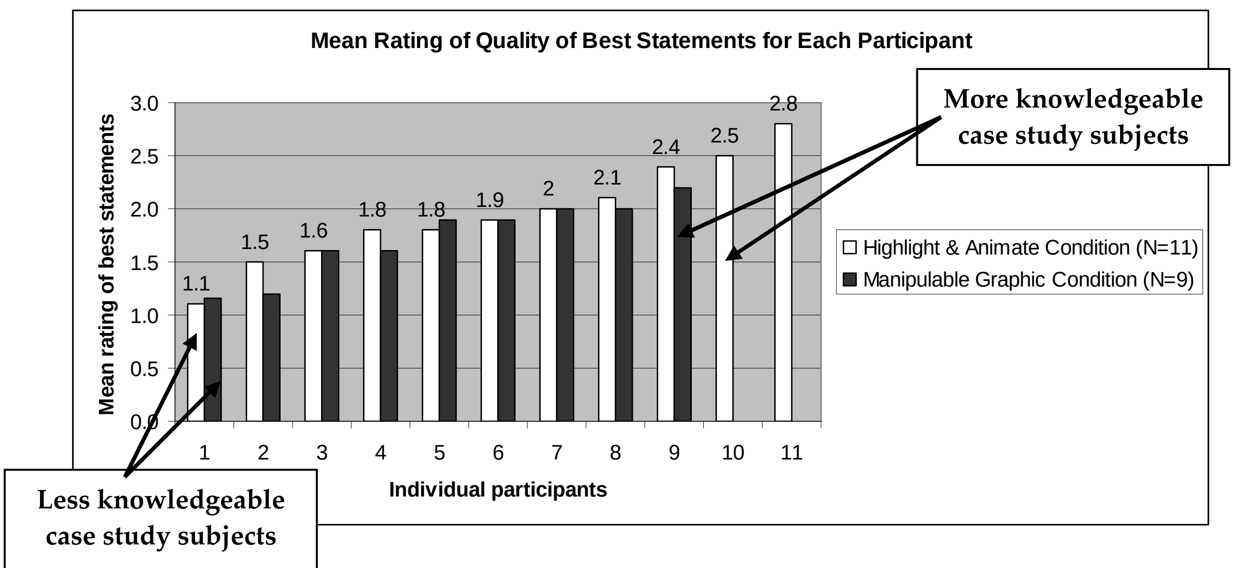

Figure 5.1
Measure of knowledge articulated: Ratings of best statements

Note that while mean rating on quality of best statements was the primary criterion for selection of case study subjects, there were other considerations as well. In order to facilitate comparisons, I chose subjects whose characteristics were comparable in some respects (e.g., reading achievement) and whose interactions with the text were informative and likely to be interpretable by others. Case study subjects had reading comprehension scores at least 1 ½ standard deviations below the mean. All produced

[14] 0=missing, 1=inadequate, 2=adequate, and 3=complete.

novel statements about the ideas of the text, rather than quotes from the text, in their interviews. Case study subjects, while not the most talkative of all subjects, did usually produce ideas in a manner that was sufficiently organized to be readily understandable.

For each subject in these case studies, a table will present data from assessments of the subject. Note that scores on the posttest of conceptual knowledge, while of interest and reported in these tables, was not among the selection criteria. Visual inspection of the data suggests that scores on the posttest of conceptual knowledge correlated poorly with the primary selection criteria for these case studies – knowledge articulated – for participants in the Highlight & Animate Condition (see Figure 5.2)[15]. However, scores on the posttest of conceptual knowledge appeared to be more closely correlated with knowledge articulated, or quality of best statements – for participants in the Manipulable Graphics Condition (see Figure 5.3).

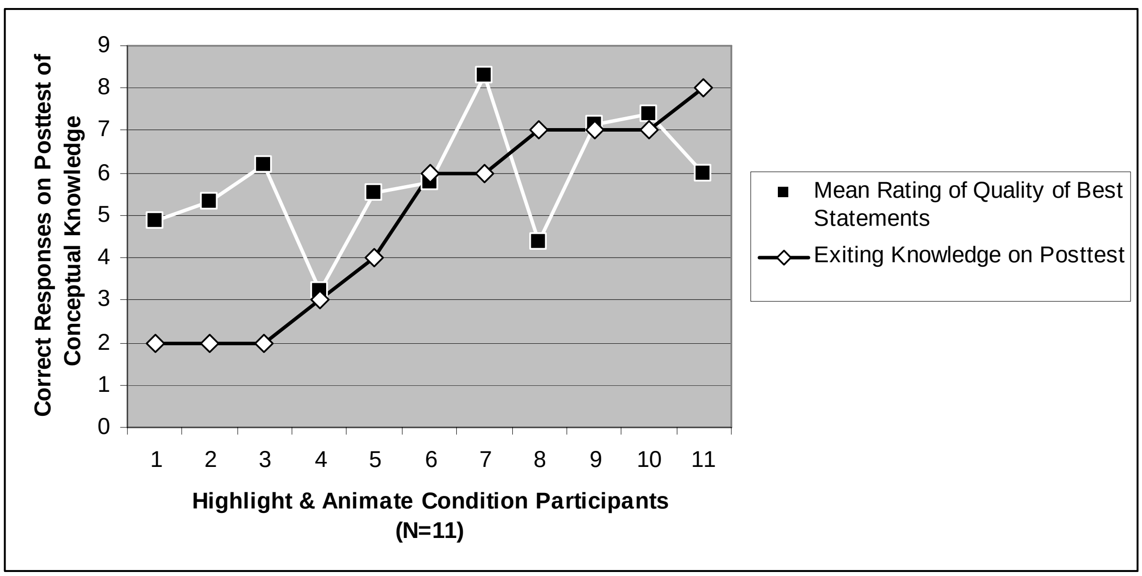

Figure 5.2
Relation between knowledge posttest score and knowledge articulated: Highlight & Animate Condition

[15] Figures 5.2 and 5.3 (like Figures 4.8 and 4.9) were designed to show the *relative relationship* between overall amount of conceptual knowledge demonstrated on the posttest and mean quality of best statements across participants within a condition. The values on the y axis may be used only to interpret the darker line of data points on each graph that show participants' exiting knowledge. The lighter line of data points represents the quality of participants' best statements. While these data for quality of best statements are represented in accurate proportion to each other, values on the y axis are not applicable to these data.

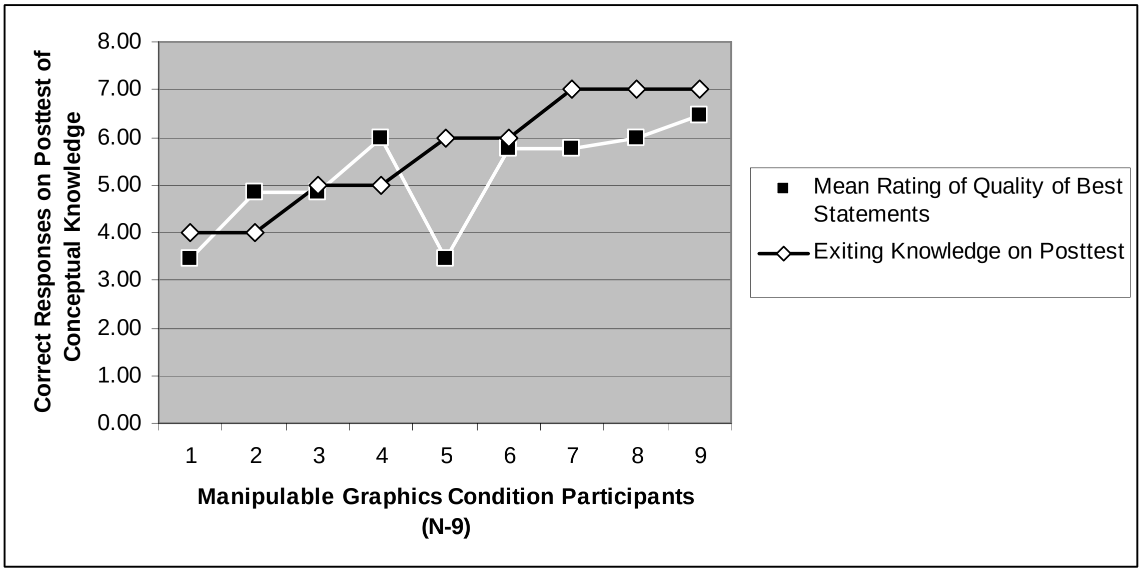

Figure 5.3
Relation between knowledge posttest score and knowledge articulated:
Manipulable Graphics Condition

These individual case studies were analyzed with these questions in mind: How did each reader interact with the ideas and the affordances of the experimental text? What was it about the interaction of the more knowledgeable participants (those with the highest quality of knowledge articulated) with the text that seemed to facilitate their learning? What seemed to be the relative contributions of the digital environment and the reader's own resources? How could the environment be more supportive? What was it about the interactions of the less knowledgeable participants (those with the lowest quality of knowledge articulated) that seemed to limit their learning? What appeared to be the contributions of the reader and of the digital environment to the reader's limited success? What would it take for less knowledgeable participants to build understanding in each condition?

In the examples of participants' responses to the experimental text, there are frequent references to pages of the text by page number. Those pages may be found, with a description of their affordances in each condition, in Appendix A.

SARAH: MANIPULABLE GRAPHICS CONDITION – LESS KNOWLEDGEABLE

Table 5.1
Sarah's incoming resources and outcome measures

Subject	Resources entering study					Outcome measures	
	Conceptual knowledge (pretest)	Text-specific vocabulary	Reading compre-hension	Word ID	General vocabulary	Rating of best statements	Conceptual knowledge (posttest)
Sarah	**5**[16]	**4**[17]	**3**[18]	**76**[19]	**92**	**1.2**[20]	**6**[21]

Sarah entered the study with several notable resources. Her knowledge about light and vision was stronger than all but one other participant in the study. Her word recognition was relatively better than her poor reading comprehension. And she enjoyed reading in the electronic environment, describing it as more accessible and supportive than conventional text.

> **"I really liked the computer because, like if you didn't want to read, you could have the computer read for you, or you have the glossary to help you, and like the important word was highlighted. [In conventional text] you would have to go all the way to the glossary in the back and [in] this [computer] you could just click on it."**

She particularly liked the **"pictures"** that she could manipulate in order to **"describe and discover"** such phenomena as **"what color's going to bounce off."**

In spite of having a reasonable amount of incoming knowledge, an appreciation of the support features of the electronic environment, and an interest in discovering the ideas depicted in graphics, Sarah demonstrated minimal evidence of learning from her

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[16] Number of items correct on 9-item pre-test of conceptual knowledge
[17] Number of items correct on 10-item pre-test of vocabulary from *How Do We See*
[18] Score is percentile on the Gates-MacGinitie Test of Reading
[19] Woodcock-Johnson word id and general vocabulary scores are standard scores: mean=100 (sd=15)
[20] Scale: 0=missing, 1=inadequate, 2=adequate, 3=complete; Mean for s3 best statements is reported here.
[21] Number of items correct on 9-item post-test of conceptual knowledge

interaction with *How Do We See*. She gained just one point on the posttest of conceptual knowledge; only 5 of her 13, 'best statements' met the criteria for 'adequate;' she never articulated an explanation or statement of a scientific principle. The following close-up of Sarah shows how she interacted with the ideas of the experimental text and the affordances of the Manipulable Graphics Condition. The discussion considers, in light of the literature cited in Chapter 2, what could have contributed to her limited success and what it might take for her to engage with ideas of the text more productively than she apparently did.

Sarah interacted with each page of the experimental text in a remarkably consistent way. She smoothly navigated to a page and activated TTS. She attended to the screen but made no spontaneous comments while, or after, the computer read the whole page to her. Then, she read aloud the '*Directions to Investigate,*' with a few false starts and substitutions that she did not correct. Silently, she moved to the diagram and manipulated it as directed. Sarah signaled the conclusion of her investigation with **"okay."** Finally, she responded to each of the interviewer's questions with one or two sentences, sometimes pausing for 15 seconds or more before answering a question about what, or how, she learned. A close look at Sarah's treatment of the prose and graphics and her reports of what and how she learned revealed that she interacted with the experimental text in a way that privileged the graphic, but did so without sufficient, clear purpose.

Sarah's reading, in the presence of a diagram, was characterized by evidence of low expectations of the prose and/or of her ability to gain a foothold in it. She did not use any vocabulary supports, though her vocabulary pretest had indicated that many important words were unfamiliar. She produced no statements (e.g., paraphrases, self-explanations, connections to her own knowledge) or questions that indicated she was fostering or monitoring her own comprehension of the prose. Nor did Sarah allow herself time to silently reflect on the prose. She had TTS read each page without pause. And, after TTS read the page, she moved immediately to the directions and the investigation. When she read the directions, she produced non-words and substitutions likely to disrupt comprehension (e.g., 'surface' for *source*, 'braker' for *beaker*, 'pros' for *positions*) without seeking assistance with pronunciation. Sarah's responses to the interviewer's questions suggested that her investigation of the diagram was often the sole source from which she constructed a representation of the text. There is no evidence of her returning to the prose, or quoting, or even remembering anything from prose.

On page 1, for example, she reported the strictly mechanical information that the amount of light coming from the headlamp changed as she moved the slider. She did not note how this change in light related to seeing inside a dark cave, which was the context set in the prose for the investigation.

> Interviewer: So what did you notice on this page?
>
> **Sarah: That like when it's** [the slider switch] **all the way up at the um, headlamp line that it, it's wide, and then when it goes down more it gets lower and lower.**
>
> Interviewer: What did you learn from all that?
>
> **Sarah: That if…** (15 second pause) **That it depends which way you want to move the thing to either get wider or darker.**
>
> Interviewer: Was the investigation helpful to you?
>
> **Sarah: Uh huh.**
>
> Interviewer: How did it help?
>
> **Sarah: Cause like…** (20 second pause) **It did because um, like it can, like you can either decide on which way you want to go if it gets darker or lighter.**

Yet, in the absence of a diagram, Sarah was able to reflect on the ideas of the prose. On page 5, which had no graphic, she responded to the interviewer's questions by closely, and mostly accurately, paraphrasing the prose:

> Interviewer: What did you notice?
>
> **Sarah: There's no picture to see like what they're talking about.**
>
> Interviewer: What did you learn?

Sarah: That the pupil allows us to see and the iris controls how much light we get and that the people see. And it reflects off the materials of the eye.

Interviewer: How did you figure that out?

Sarah: Hmm, from this paragraph.

For Sarah, the opportunities to offload the work of reading to TTS and then investigate the graphic, without any structure that compelled her to reflect on or connect the actions of the graphic with the descriptions and explanations in the prose, may have diminished the important potential contribution of the prose to her learning from the text.

Sarah's treatment of the graphics suggested that she required support to understand, explain, and evaluate scientific representations. The Manipulable Graphics Condition provided only a portion of the metarepresentational support she needed. This was apparent in the 'nearsighted' quality of her descriptions of what happened to "it" in her investigations. Also, Sarah needed assistance to set scientific purposes for her investigations. The Manipulable Graphics Condition did not make the structures of scientific inquiry sufficiently explicit. This is apparent in Sarah's less-than-systematic means of investigating multiple variables.

Sarah's descriptions of her investigations showed that the Manipulable Graphics Condition enabled her to identify and 'zoom in' on important aspects of the diagram, made salient through animation (e.g., the width of the beam on the caver's headlamp in Figure 1, or whether or not the arrow – representing reflecting light – traveled to the eye in Figure 2). She did not, however, then take the necessary step back to see how those specific aspects functioned as part of a larger whole. In focusing on just the procedural aspects of the graphic and not the context, Sarah was likely to miss the message behind the graphic. For example, when describing Figure 1 (page 1 example above), Sarah focused on the direct relationship between the actions she took in moving the slider and the resulting change in the size of the beam width/intensity of the light. She did not note, as many other readers did, that the light was on the helmet of a person exploring the cave and that when the light was turned out the cave was completely dark.

There is evidence in Sarah's responses to interview questions that her manner of using the Manipulable Graphics Condition – attending to the diagram, to the exclusion of the prose – limited her interpretation of the diagrams and understanding of the concepts they represented. Certainly, the Manipulable Graphics Condition did not facilitate Sarah's communication about the big ideas of *How Do We See*. Her responses to the text were remarkable as much for what she said as for what she did not say. She made numerous statements about "it" without clear verbal or nonverbal (e.g., point with cursor) referents. And, she never used a number of words that were critical to the important ideas in the text. For example, she never referred to the phenomena of 'light' and she never spoke of 'seeing' something. She did not mention the structural or functional relationships of parts of the eye. Arguably, these were major omissions in responses to a text about how light enables us to see, suggesting that Sarah may not have understood that the arrow represented light, nor that the arrow from an object to the pupil indicated that the object could be seen.

Evidence from Sarah's transcript indicates that she was not sufficiently familiar with the process of purposeful scientific inquiry to independently structure an organized and thorough investigation of multiple variables. The Manipulable Graphics Condition provided the raw materials for inquiry, but not direct instruction in the inquiry process. The *Directions to Investigate* addressed only the mechanics of animating the diagram (e.g., for Figure 2: to move the book, click on the words Left, Right, or Center; to show a light ray, click on the number). The directions did not organize reader moves around an explicitly stated purpose. Consider Figure 2, where both the sources of light and the position of the book could be changed. Sarah followed the directions to move the book around and show the different light rays. But, with no guidance in how to do so, she did not systematically activate each light source with the book first in the left, then right, and finally center positions. Consequently, she found spurious patterns rather than principles of scientific relationships. Her conclusion, which was consistent with her observations but erroneous, was that only **"numbers"** (numbered light sources) **"in the middle"** (position) put the **"line"** (light ray) on the eyeball.

In summary, it seemed that what was most accessible and therefore most salient about the Manipulable Graphics Condition for Sarah were the opportunities to manipulate the graphic. Thus, she focused her attention on these opportunities – to some advantage in that she observed phenomena, an important step in scientific inquiry – but also to her disadvantage in that she ignored the important information in the prose that would enable her to set a purpose for, and interpret the results of, her inquiry. However, Sarah was able to treat the prose as an information source rather than a hurdle, as seen on the one page that the prose did not stand between Sarah and a Manipulable Graphics. It seems that Sarah might learn much more from the Manipulable Graphics Condition if provided with explicit instructions about how and why to manipulate the diagram and scaffolding in how to interpret her observations in light of the context set in the explanations of the prose.

OLIVIA: MANIPULABLE GRAPHICS CONDITION – MORE KNOWLEDGEABLE

Table 5.2
Olivia's incoming resources and outcome measures

Subject	Resources entering study					Outcome measures	
	Conceptual knowledge (pretest)	Text-specific vocabulary	Reading compre-hension	Word ID	General vocabulary	Rating of best statements	Conceptual knowledge (posttest)
Olivia	2[22]	5[23]	5[24]	89[25]	94	2.2[26]	7[27]

The resources that Olivia brought to the study were remarkable for her minimal knowledge about the topic of light and vision. Her conceptual knowledge pretest score of two items correct was the second-lowest score that any participant in the study obtained. Yet, after reading *How Do We See* in the Manipulable Graphics Condition , Olivia was able to answer seven items correctly on the posttest of conceptual knowledge – a gain of

[22] Number of items correct on 9-item pre-test of conceptual knowledge
[23] Number of items correct on 10-item pre-test of vocabulary from *How Do We See*
[24] Score is percentile on the Gates-MacGinitie Test of Reading
[25] Woodcock-Johnson word id and general vocabulary scores are standard scores: mean=100 (sd=15)
[26] Scale: 0=missing, 1=inadequate, 2=adequate, 3=complete; Mean for s3 best statements is reported here.
[27] Number of items correct on 9-item post-test of conceptual knowledge

5 points over her pretest score and the highest gain, achieved by only three participants in the study. Arguably, Olivia had plenty of room for growth on the conceptual knowledge measure. However, Olivia also provided other evidence of productive use of the experimental text. She produced the most conceptually complete best statements of any participant in the Manipulable Graphics Condition and she produced no inadequate ones. Thus, Olivia was chosen as an example of a more knowledgeable participant in the Manipulable Graphics Condition.

Examination of Olivia's transcripts showed that her interactions with the ideas and the affordances of the experimental text were characterized by attention to, and integration of, both prose and graphics. With respect to her use of prose, there is evidence that she read and interpreted challenging vocabulary using only contextual support. For example, despite difficulty recognizing some words, Olivia read all of the prose including captions on the figures, on her own. While the interviewer corrected miscues on a few unfamiliar words (e.g., beaker, syringe), Olivia monitored and corrected most miscues on her own without TTS support. Olivia never fostered her own understanding of words by means of the vocabulary support tools. When asked about this she said, "I didn't think I needed to because I knew a lot of the words." Though her vocabulary pretest score would suggest that she did not know some of the words well, Olivia apparently figured out how to apply the vocabulary correctly as she paraphrased ideas. In the following example from page 2, Olivia corrected her initially incorrect application of the word 'absorb.'

> Interviewer: What did you notice?
>
> **Olivia: When the light source like hits the black, it doesn't absorb to people's eyes.** (initially wrong) **But when it hits white or other colors, it goes to your, it doesn't absorb the light but it goes to your eyes.**
>
> Interviewer: What did you learn from that?
>
> **Olivia: That when the light bounces off something, if it's not black it goes to your eyes. But if it's black it absorbs the light.** (now correct)

There is evidence that Olivia recalled and integrated information from the prose with what she learned from the graphic. Her responses to interview prompts to say what she noticed or learned, always adequate, often contained words and ideas that could have only come from the prose. And, she acknowledged the prose as the source of what she had learned.

> Interviewer: (page one) What did you learn?
>
> **Olivia: That if you're in a cave and you're there by yourself, and the headlamp like goes down, you can't see your hands or anything.** ('hands' are only mentioned in the prose, not represented in graphic)
>
> Interviewer: How did you figure that out?
>
> **Olivia: From reading the um, text.**
>
> Interviewer: (page three) What did you learn?
>
> **Olivia: The light source when it like, when you see something? It goes right to your pupil and then goes to your brain, and then it tells you what you see.** ('the brain tells us what we see' is from the prose and not represented in the graphic)
>
> Interviewer: So, how did you figure out that part?
>
> **Olivia: From reading the text.**

Olivia returned to the prose one more time than most participants in the Manipulable Graphics Condition. At the end of the interview for each page Olivia was asked, 'is there anything else you want to add?' In answer, Olivia returned to silently study the prose for 15-20 seconds and then quoted or paraphrased a statement from the prose. Olivia's repeated attention to the prose, integration of information from the prose with descriptions of phenomena depicted in graphics, particularly in her own combination of words, and skill in inferring the appropriate use of scientific vocabulary all were likely contributors to her ability to articulate the important ideas of the text.

Evidence that Olivia found the graphics more compelling and perhaps more accessible than the prose comes from several sources. For example, she commented that page 8 was her least favorite page. The prose on this page provided an informative, if brief, account of the structures of the eye that enable us to see colors. The graphic was a simple circle of colors with minimal opportunities for interaction. Olivia reported that **"there was not**

very much to think about" on that page. Also, Olivia reacted affectively to events in the graphic (only), exclaiming, **"wow!"** when the cave went very dark on page one, **"wow!"** again when the iris changed size on page four, and **"ahhh…"** when each shade of gray light reflected less than white but more than black on page 6. Olivia described why she liked the Manipulable Graphics Condition : **"You could like investigate what you could do to it. So you could see what would really happen – when you were in that situation."**

Olivia constructed meaning most effectively when her investigation of the graphic was systematic. That is, where there were two or more aspects of the graphic that could be manipulated, an investigator needed to hold one feature constant while systematically changing another, in order to infer the relationship between the features. The directions to investigate did not make such an organization of the investigation explicit. Olivia was able to organize her investigations in a logical fashion. For example, on page 2 the multiple variables were the position of the book and the location of the source of light. Olivia held the book constant in first the left, then the right positions while she activated each light source in turn. As a result, she was able to articulate some of the conditions under which light did and did not reflect.

While Olivia's investigations were systematic, they were often not thorough. For example, on pages 2, 3, 4, and 7 she tried about half of the possible moves she could have made. Thus, she stated conclusions that were drawn from partial evidence, often lacking in detail, and sometimes lacking in accuracy. For example, on page two she never held the book in the center position while activating each light source. Thus, she observed light reflecting and being absorbed, but not light being blocked. So, information that light could be blocked was missing from her statement about circumstances under which light did not reflect. There was no indication (e.g., no predictions about what would happen, no confirmation) in these brief investigations that Olivia tested any new hypotheses of her own that she may have developed in the course reading the prose or studying the figure – though this was an anticipated application of the investigation.

In addition to her abilities to be wowed by the graphic and to conduct a logical investigation, one other aspect of Olivia's interpretation of the graphics seemed to contribute to her developing knowledge about light and vision. Olivia accurately interpreted some basic – albeit critical – concepts portrayed in the graphics. For example, she understood that the arrows represented light and when the arrow was shown in contact with the pupil, the person could see. These metarepresentational understandings directed her to the important ideas to be gleaned from the opportunities to manipulate the diagram. So, rather than focus narrowly on just the portion of a figure to which the manipulation directed her, Olivia was inclined to see evidence in the figure of how or what we see.

Among the lessons to be learned from Olivia's productive use of the Manipulable Graphics Condition – and from Sarah's less fruitful experience in the Manipulable Graphics Condition – are the following. These readers were likely to interpret opportunities to manipulate a diagram as an invitation to focus on the diagram. As struggling readers they were likely to focus on the more accessible diagram to the exclusion of the less accessible prose. Much was lost when these readers vaulted over prose as a hurdle in the path to the diagram. Prose could have provided information needed to understand the representational qualities of the diagram (e.g. the significance of color, the meaning of an arrow, the importance of the relative positions of objects). Prose was necessary to set the context, purpose, method, and a means of interpreting observations of an investigation. For these readers, it seems that if opportunities to investigate were to be fruitful, they would need to be accompanied by 1) explicit guidance in what they should expect (demand) of both prose and graphics, and 2) careful scaffolding in the process of integrating prose and graphics

MARY: HIGHLIGHT & ANIMATE CONDITION – LESS KNOWLEDGEABLE

Table 5.3
Mary's incoming resources and outcome measures

Subject	Resources entering study					Outcome measures	
	Conceptual knowledge (pretest)	Text-specific vocabulary	Reading compre-hension	Word ID	General vocabulary	Rating of best statements	Conceptual knowledge (posttest)
Mary	0[28]	4[29]	7[30]	78[31]	89	1.1[32]	3[33]

Mary's score on the pretest of conceptual knowledge – 0 – suggested that she approached the task of reading *How Do We See* in the Highlight & Animate Condition with very little background knowledge about light and vision. Even more problematic was the attitude with which Mary approached the pretest and, it seemed, any school-related task. Gathered with a small group of classmates to take the pretests, Mary took the opportunity to "hold court." She called the girls to her table and banished the boys to another. She directed those around her, assigning seats and dictating who got what color souvenir U of M pencil to take the tests. In spite of requests for her attention, she continued to tell stories and talk with the other girls until isolated under close guard at a remote table. Mary was sufficiently disruptive in her classroom that she was frequently in trouble and then suspended from school for several days during the course of the study. Clearly, Mary was ill-prepared in terms of school habits, background knowledge, and reading skill to learn about light and vision from a challenging text. Thus, her high level of engagement as she began to read *How Do We See* was especially remarkable.

As she began to read the text, Mary made a number of moves that indicated that she was calling on her own resources as well as the affordances of the digital environment to

[28] Number of items correct on 9-item pre-test of conceptual knowledge
[29] Number of items correct on 10-item pre-test of vocabulary from *How Do We See*
[30] Score is percentile on the Gates-MacGinitie Test of Reading
[31] Woodcock-Johnson word id and general vocabulary scores are standard scores: mean=100 (sd=15)
[32] Scale: 0=missing, 1=inadequate, 2=adequate, 3=complete; Mean for s3 best statements is reported here.
[33] Number of items correct on 9-item post-test of conceptual knowledge

make sense of the text. Some of her cognitive and metacognitive strategies could be inferred from what she said and did. She tacked back and forth between prose and graphic in response to the Highlight & Animate opportunities. She connected events in the text to her experiences. She used the vocabulary tools to monitor that words made sense. She questioned what puzzled her. It is hard to say, however, what cognitive or metacognitive activities Mary was engaged in during the frequent times that she silently studied the text.

On page one, Mary read aloud accurately, carefully tracing words with the cursor as she read. She neatly activated the first Highlight & Animate Feature without a reminder to do so, then paused for twenty seconds to study the figure and review the highlighted sentence. She read aloud the caption on the figure, words that most participants ignored, and again paused to study the page. She sought glossary support for 'evidence' and 'illuminating' and clarified what was not clear to her in the figure, "is it a girl?" In response to the interview questions she accurately described the situation depicted on page one and the inference that she drew – an important idea with respect to the specific example on the page, if not the preferred response of a general scientific claim. She cited her own knowledge of famous persons as one source for her inferences.

> Interviewer: What do you notice on this page?
>
> **Mary: It's a girl inside the cave. She's looking at things and she got a headlamp on her head to see what that is.**
>
> Interviewer: What have you learned?
>
> **Mary: You do need to see light in a cave because you could trip over something probably if you don't have no light. And you need your eyes to help you see. So you won't crash into nothing or anything, or anyone.**
>
> Interviewer: Hmm. How did you figure that out?
>
> **Mary: Because if she didn't have any eyes, she could have crashed into something in this cave. But you can't just be like Ray Charles or Stevie Wonder that you just can't feel or touch anything automatically. You got to get used to it.**

Mary's success in making sense of *How Do We See* was short-lived. The experimental text quickly became more conceptually complex. Page two presented three related, technical ideas for which Mary apparently had minimal prior knowledge with which to build new knowledge. Mary approached page two with the same moves as for page one – she read, monitored her own accuracy, interrupted the reading to activate each Highlight & Animate symbol, studied the highlighted words and animated figure, spontaneously verbalized an understanding, and looked up words in the glossary. But, the resources that were sufficient for the one, rather familiar idea that introduced the text on page one did not suffice for all of the scientific ideas of page two. In her answer to the first interview question Mary indicated dissatisfaction with how well she explained what she noticed.

> Interviewer: What do you notice about this page?
>
> **Mary:** (quiet for 14 seconds while examining the figure) **That a person that's looking at that** (gestures from person's eye to book on table), **he can't see the penny** (gestures to penny behind book) **because, because it refle-, it reflect, I think it, something like that…**

Mary's silence in response to the next interview prompt for page two could be interpreted in a number of ways. Her question (below) provided evidence that she did not understand either some of the ideas presented in the highlighted prose or the significance of the animated aspects of the figure. Possibly, her silence also indicated uncertainty about how to proceed in the face of her awareness of her limited understanding, since the Highlight & Animate Feature, which was supposed to help her make sense of the ideas, was not meeting her expectations. Unfortunately, when Mary took the initiative to improve her own understanding by calling upon another resource – the interviewer – that course of action also proved unsatisfactory. The interviewer, following the study protocol, could not answer her questions and so directed her back to the text with open-ended questions.

> Interviewer: Well what did you learn from all this? (no response for 45 seconds) What did you figure out? (no response for 25 seconds) What can you understand now that you didn't know before?
>
> **Mary:** (reactivating the 2nd and 3rd Highlight & Animate symbols, studying them for 30 seconds) **Um. What do this mean? 'In the figure light rays that strike back parts on the panda do not reflect?'**

Interviewer: Hmm. Yeah, what do you notice about that? (no response for 15 seconds) What do you think this means? (no response) Were these helpful to you, these animator buttons?

Mary: Not really. They didn't hardly show anything.

Just how frustrating this experience was to Mary became clear after she finished reading the text and reflected on the experience. She spoke specifically of page two.

Mary: This is my worstest page … the hardest one out of all the pages.

Interviewer: You really don't like that page. What don't you like about it?

Mary: It's confusing. The whole thing, it's just confusing. Plus it's the stuff that you asked. They're confusing on the page that looks confusing.

However, the other pages provided their own challenges. Thus, the pattern that was set in the unfruitful exchange regarding page two continued for the rest of Mary's interactions with the experimental text. In spite of her efforts to use her own resources and the affordances of the digital environment, Mary was able to respond to only half of the 'what did you notice' prompts with even a partial description of the phenomena of interest. 'What did you learn' was generally met with prolonged silence. Mary never stated a scientific principle or general application of the specific example on the page and seemed aware of this lapse. She described the Highlight & Animate Feature as her **"worst favorite, worst tool"** and often expressed frustration that the Highlight & Animate Feature did not support her learning, as in this exchange.

Interviewer: Was the animator (participants' name for the Highlight & Animate Feature) helpful?

Mary: They're not helpful enough for me. Yeah, cause they didn't hardly do anything.

Mary became gradually less animated and engaged as she progressed ever more unsatisfactorily through the text, insufficiently supported by her own knowledge and the affordances of the digital environment. She intermittently shifted the burden of reading to TTS, though she had read aloud well. She gradually stopped using the glossary though she had enjoyed discovering word meanings. She continued to activate the Highlight &

Animate symbols, but seldom revisited them and spent progressively less time studying the figures and reviewing the highlighted words. She plucked words right from the prose more than she put ideas into her own words. And she stopped asking questions that never got a direct answer. Conversations between Mary and the interviewer became truncated.

In summary, a child who had difficulty engaging productively in school tasks found the digital environment sufficiently intriguing to enthusiastically (at first) engage with the text and the interviewer around conceptually challenging ideas. The environment worked well for Mary when the text presented minimal conceptual challenges and required little prior knowledge of the topic. Once the concepts were complex and/or unfamiliar, the features of the environment were not sufficient to scaffold her understanding. Ultimately, Mary, who brought little knowledge of her own about the topic of the text, found her interactions with the digital environment (and her conversations with the interviewer) to be dissatisfying. However, outside of the research setting and the guidelines of the research protocol that constrained the opportunities to respond to Mary's questions and point out connections between the prose and the graphics, this need not be the case. While the understandings that Mary articulated in her initial interactions with the text were not sufficient for her to develop the big, important ideas on her own, surely they would provide a starting point from which to build more nuanced conceptions with the scaffolding of peers and instructors.

Mary is a little different from other participants. She asked a number of questions which revealed her partial understandings and, sometimes, additional information needed to make sense of the text. Other 'less knowledgeable' participants seldom did so. And, Mary expressed her disappointment with the experience; no other participant reacted negatively to the digital environment. Thus, for this 'less knowledgeable' participant, I was able to capture some of the mismatch between the ideas of the text, her limited understanding of those ideas, and her (thwarted) expectations of the interviewer and the experimental features of the digital environment to facilitate her understanding. Mary's experience is particularly helpful in highlighting the insight that some participants needed guidance and feedback even in the highly directive context of the Highlight & Animate Condition

MIKE: HIGHLIGHT & ANIMATE CONDITION – MORE KNOWLEDGEABLE

Table 5.4
Mike's incoming resources and outcome measures

Subject	Resources entering study					Outcome measures	
	Conceptual knowledge (pretest)	Text-specific vocabulary	Reading compre-hension	Word ID	General vocabulary	**Rating of best statements**	**Conceptual knowledge (posttest)**
Mike	5[34]	6[35]	5[36]	96[37]	113	2.5[38]	7[39]

Mike was chosen on the basis of the quality of his knowledge articulated as an example of a participant who used the Highlight & Animate Condition productively. He articulated all of the important ideas of the text adequately. Mike brought several resources to his reading of *How Do We See*, some of which can be quantified on the basis of pre-assessments. For example, he entered the study with some of his own knowledge on the topic of the experimental text, answering 5 out of 9 questions correctly on the pretest of conceptual knowledge, the second-highest score participants obtained. His vocabulary was strong. Though his text-specific vocabulary knowledge was about average among participants in the study, his general vocabulary was one standard deviation above the mean for grade. While reading comprehension was well below the mean for grade, his word recognition was relatively better. Mike was eager to participate in the research, describing the computer as **"fun"** and the ideas to be studied as **"pretty interesting."** His positive attitude was apparent in his review of his experience.

> Interviewer: So, which was your favorite page?
> **Mike: Um, three. Three was one of them.**
> Interviewer: Okay.

[34] Number of items correct on 9-item pre-test of conceptual knowledge
[35] Number of items correct on 10-item pre-test of vocabulary from *How Do We See*
[36] Score is percentile on the Gates-MacGinitie Test of Reading
[37] Woodcock-Johnson word id and general vocabulary scores are standard scores: mean=100 (sd=15)
[38] Scale: 0=missing, 1=inadequate, 2=adequate, 3=complete; Mean for s3 best statements is reported here.
[39] Number of items correct on 9-item post-test of conceptual knowledge

Mike: Two.

Interviewer: *Uh huh.*

Mike: And four.

Mike's resources were not unusual. That is, other participants demonstrated equivalent or better reading comprehension, word recognition, conceptual and vocabulary knowledge specific to the text, and a desire to work with the computer. Yet in spite of equivalent resources, their quality of knowledge articulated was not nearly as high as Mike's. What was it about the way in which Mike used his resources in coordination with the affordances of the digital environment that enabled him to make sense of the ideas of *How Do We See* in a way that was so productive?

Mike approached each of the six pages with Highlight & Animate symbols using a consistent pattern of moves. He read aloud with a number of self- and interviewer-corrected miscues, mostly substitutions and phrasing errors. He interrupted his reading at each Highlight & Animate symbol, clicked on the symbol, and traced the action of the animated portion of the graphic with his cursor. He confirmed, with language paraphrased from the prose, that the phenomenon described in the highlighted sentence had indeed been demonstrated in the graphic. Then, he sought glossary support for every word in blue font – even if he had looked it up on another page. Finally, he responded to the interviewer's questions in sentences that were well organized and a manner that was confident, producing all of the important ideas on the page, either partially (describing the phenomena depicted) or completely (providing an explanation for that phenomena).

Analyses of these interactions with the text, informed by the landscape model of comprehension, suggest that Mike built coherent representations from immediate segments of text and segments across a page, as well as from his own knowledge of the topic. He used several strategies including summarizing, explaining, paraphrasing, and integrating information. The affordances of the Highlight & Animate Condition seemed to guide Mike to advance his own understanding of some ideas, though it seemed he arrived at other understandings quite on his own.

Mike’s use of text prompts was unusual among participants in that he integrated some prose and graphic information in response to only the conventional prompts embedded in text to direct the reader to a figure. Even before he used the Highlight & Animate Feature on page one, Mike responded to the parenthetical note ‘see figure 1,’ by interrupting his reading to turn to the figure and confirm that the figure did depict the phenomenon described in the prose. Mike complied with the ‘see figure _’ directive on other pages by as well by paraphrasing prose and describing and elaborating on the figure.

> **Mike:** (reading) **There is an evidence that we need light to see deep in a cave where there is no sunlight. There has to be another source of light for us to see what is in the cave. See Figure 1.**
>
> **Mike:** (interrupted reading to identify ‘another source of light’ in the figure) **And it’s, it says, ‘headlamp.’ It has a guy with a helmet that has a lamp on there so he can see. And then I see light here, which is shining, just in case of this goes out, he can still see with this.**

Given that Mike connected some graphics to prose in response to conventional prompts, it is not surprising that he did so in response to the Highlight & Animate Feature. After activating each Highlight & Animate symbol, his spontaneous comments indicated that he again confirmed that the phenomenon depicted in the graphic was consistent with the information reported in the highlighted prose, as he did here for page two.

> **Mike:** (reading) **Figure 2 shows light striking at a penny and a book. The light reflected from the cover of the book reaches the person’s eyes so he can see the book.**
>
> **Mike:** (activated Highlight & Animate Feature here and confirmed that figure and prose are aligned) **And it shows us how it did that.**
>
> **Mike:** (resumed reading) **Scientists have observed that black materials do not reflect light. In the figure light rays it, that strike black parts of the panda do not reflect.**

> **Mike:** (activated Highlight & Animate Feature and responded to explain the event of the highlighted last sentence) **Because the light is absorbed from it.**

What was remarkable about Mike's attention to the highlighted words and animated figures of the Highlight & Animate Condition was that he consistently went beyond proposition-level understanding to build a representation that encompassed all of the highlighted and animated information on a page. Mike gathered information from each Highlight & Animate opportunity as he read the page and then, in response to interview questions, provided an overview of the big picture as well as the details. So, after reading about and observing a demonstration of how light interacted with the pupil, retina, and optic nerve on page 3, Mike produced the following statement summing it all up.

> Interviewer: Tell me what you notice here.
>
> **Mike: Um, I noticed that there's a lot of parts that have, that have to work to get the signals to your brain so you can know what you see. And I learned that some, that there's an optic nerve, there's… the retina carries the signals to the, well the retina turns the light into the, into signals and carries them to the optic nerve, which carries, which the optic nerve carries to our brain… and** [it] **happens so quick like** [snaps his fingers].

In this way, Mike captured in his own words several big ideas that eluded many other readers of *How Do We See.* For example, on page 4 Mike provided an overview of the function of the iris rather than, as most reader did, a description of the more familiar action of the pupil changing size in response to changes in light.

> **Mike: Um, I learned that the iris controls the whole, controls the pupil and how big and how small it goes and how much light comes in and shows us, hmm, that's pretty much it.**

And again, on page seven he stated a concept which readers rarely extracted from their observations of a prism separating light into colors.

> **Mike: Um, I learned that white light is actually colored light.**

It seems that though Mike came with some knowledge of the topic, he worked to build new knowledge, not just confirm what he knew. For example, he knew of some circumstances under which light did and did not reflect, but was able to add another after reading page two.

> Interviewer: Tell me what you noticed on this page.
> **Mike: Um, I noticed that it was a review over in fourth grade. Because we did light in fourth grade, how it reflected and how black objects absorb the light.**
>
> Interviewer: Did you learn something from this page?
> **Mike: Yes, I learned that um some things that are blocked by other things, like light, when light is blocked by an object you can't see with your eyes.**

It must be pointed out that just as Mike was not the only participant to bring resources such as knowledge of the topic to his work with the experimental text, he was not the only participant to use those resources productively in the Highlight & Animate Condition. Three other participants in the Highlight & Animate Condition were able to articulate their knowledge of the important ideas of the text nearly as well as, or better than, Mike did. All of these participants who used the Highlight & Animate Condition productively had in common at least moderate knowledge of the topic of the text (a score of 4, 5, or 6 out of 9 items on the pretest of conceptual knowledge). This observation raises the question: how can we support those, who like Mary began with little knowledge of the topic and thus limited sources of information for building even proposition-level understandings, when they need to build coherent representations of larger segments of text?

It seems that there are potential answers to this question in the experiences of those in the Manipulable Graphics Condition. In contrast to the Highlight & Animate Condition, prior knowledge did not prove to be an advantage in the Manipulable Graphics Condition. Those in the Manipulable Graphics Condition who produced both the greatest knowledge gain and the highest quality of knowledge articulated were those who approached the text with the lowest incoming knowledge score on the pretest of conceptual knowledge.

One wonders if Mary, who was limited by minimal knowledge of the topic, could be guided to first build her own knowledge by investigating the phenomenon in a manipulable graphic. (Recall that even those in the Manipulable Graphics Condition who articulated knowledge well tended to do so with a focus on the specific examples on a page, rather than the big scientific principles illustrated.) Then, using Highlight & Animate-type prompts, which clearly had encouraged her to direct her attention to both prose and graphics, she could be supported to use some of the strategies (e.g., paraphrasing the portion of the highlighted sentence that corresponded to the event depicted in the animated graphic, providing an explanation from the prose for the animated phenomenon) that Mike and his high-performing peers used to construct coherent representations of the scientific principles developed across the pages of *How Do We See.*

In the following chapter, I draw upon the analysis of the individual experiences of the four case study participants as reported in this chapter as well as the analysis of affordances and analysis of ideas from Chapter4 that described trends across the experimental groups. I use those analyses to highlight findings and to consider implications of the study reported here. I also offer recommendations for future research regarding the design of supported electronic text.

CHAPTER 6: CONCLUSIONS

This study was an investigation of the effects and affordances of two features of a digitized, graphic-rich informational text – a Highlight & Animate Feature and Manipulable Graphics. I sought to discover if fifth grade struggling readers gained knowledge of the topic of the experimental text as they interacted with the text using the experimental features. The results of the study revealed that participants understood and articulated conceptually challenging ideas when their interactions with the experimental text were supported by features that facilitated the interpretation and integration of graphics and prose. I also examined the nature of readers' interactions with the text using the experimental features. In the concluding chapter of this dissertation I highlight several important findings regarding the ways in which the Highlight & Animate Feature and Manipulable Graphics mediated readers' interactions with the experimental text. I discuss the implications of these findings for the design of multimedia learning environments and the instruction of struggling readers learning from digitized texts. Limitations of this study will be described and suggestions for future research will be offered.

Highlights

In this section I summarize the ways in which the Highlight & Animate Feature and the Manipulable Graphics mediated readers' interactions with the experimental science text. I will highlight findings regarding the advantages and disadvantages of the two experimental features that were the objects of this investigation.

Struggling readers actively engaged with the experimental text in ways particular to each condition, which facilitated their own comprehension.

Struggling readers actively engaged, affectively and cognitively, with a grade-level informational text. They did so in spite of limited knowledge of the topic and poor reading achievement. Participants clearly enjoyed their interactions with the text. They were eager for their ‘turns’ and rarely needed breaks or encouragement to continue working. They navigated the digital environment with confidence and reported what they learned with minimal prompting. They exclaimed over discoveries and asserted that the computer helped them learn. Contrary to expectations that the Manipulable Graphics Condition would be the more engaging one, readers showed comparable engagement in both conditions. In this highly motivated state readers engaged cognitively with the text, using moves prompted by the affordances unique to each condition. In the Highlight & Animate Condition readers first responded to the text by reviewing, alternately, the highlighted prose and its corresponding animated graphic. This move was often accompanied by self-explanation. Readers then made other moves that could facilitate comprehension: summarizing, questioning, and identifying confusion. In the Manipulable Graphics Condition readers explored each graphic, manipulating it. These investigations led readers to make additional moves with the graphic that could support comprehension: describing action or events, connecting the events of the graphics to each other, or to their own experience. As anticipated, participants responded to their experimental conditions by actively monitoring and fostering their own comprehension.

Struggling readers met the lexical, graphic, and conceptual demands of the text in proportion to the extent to which they coordinated graphics and prose.

Participants adopted the vocabulary, interpreted the graphics, and articulated the important ideas of the text with variable consistency and depth of understanding. The quality of the lexical, graphic, and conceptual knowledge that participants articulated depended on the demands of the text and the support available in each experimental condition.

The prose of the experimental text included key vocabulary necessary to communicate ideas about light and vision. Participants in both conditions read the same prose, but had different opportunities to review it. When participants reported what they noticed and learned in their investigations, they adopted the key vocabulary of the text in proportion to their opportunities to review the prose. Participants in the Highlight & Animate

Condition, who frequently referred to the highlighted prose while studying the animated graphic, were likely to use the vocabulary of the text. Those in the Manipulable Graphics Condition, whose attention was usually focused solely on the graphic, were much less likely to use the vocabulary of the text.

The animation depicted how multi-step, abstract processes (e.g. structures of the eye conducting messages to the brain), which are not usually available to perception, might be visualized. In the Highlight & Animate Condition processes were (1) represented in graphics in a step-by-step manner and (2) linked to an account of the process in prose. Participants in this condition often attended to aspects of the graphic that were critical to interpreting these processes correctly. In the Manipulable Graphics Condition participants were (1) expected to discover processes in the course of their own investigation and (2) not directed to relevant prose nor guided to structure a purposeful investigation. Participants in this condition were comparatively more likely to attend to interesting but peripheral aspects of the graphic. They assumed, logically enough, that an idea presented in the opportunities to investigate the graphic must be deserving of attention.

Participants who demonstrated the deepest knowledge of the ideas of the text inferred, from particular examples, a general, important scientific principle (e.g. we see when light is reflected from an object). Participants in the Highlight & Animate Condition, in which the graphic that depicted the phenomena was linked to a highlighted, written explanation of the phenomena, were often able to articulate the important ideas in terms of general scientific principles. Participants in the Manipulable Graphics Condition, in which prose and graphics were not linked and participants rarely reviewed the prose, articulated the important ideas relatively more often in terms of specific events than of general principles. That is, their exploration of the graphic frequently led to procedural, rather than conceptual, knowledge.

Struggling readers with little topic knowledge gained a foothold in challenging ideas; others with modest topic knowledge advanced their understanding.

The understandings expressed and the means by which participants achieved these understandings varied with the affordances of each condition and with participants’ knowledge of the topic and of scientific procedures. Participants with the most limited knowledge of the topic found the Manipulable Graphics Condition to be advantageous. By manipulating the diagram, which was arguably more accessible than the large block of prose, they gained at least procedural knowledge of phenomena . For example, a critical concept in *How Do We See* is that we see when light is reflected from an object. The object pretest confirmed that this was an unfamiliar concept to most participants. This knowledge potentially afforded entrée to more conceptually challenging ideas.

There are two caveats to this finding. First, manipulation of the diagram was most productive when it was structured in a manner consistent with scientific testing. That is, with a clear purpose, following well-organized steps, and without a detour to examine peripheral details. Since the Manipulable Graphics Condition did not structure the investigation in this way, it was incumbent upon the participant to bring such knowledge of scientific procedures. Some did not. Second, participants required reference to the conceptually challenging ideas, as set forth in the prose, to advance from procedural to conceptual knowledge. Contrary to expectations, the experience of manipulating the diagram rarely prompted readers to return to the prose to seek explanations for the phenomena they observed. Readers were not likely to have identified and remembered the explanation from a single, often disfluent, initial reading of the very dense prose.

Participants with relatively more knowledge of the topic already knew some of the procedural information that might be gleaned from manipulating the diagram. They found support to extend this knowledge in the Highlight & Animate Condition. The Highlight & Animate Condition presented important ideas in carefully thought-out sequences of concurrent visual and verbal forms. This presentation assured that the investigation would proceed according to the norms of scientific practices. Explicit links between graphics and explanations of those graphics in the prose prompted participants to consider not only how phenomena worked but why. Those who reviewed the prose were likely to articulate deeper, conceptual understandings of the ideas of the text.

Again, there are two caveats. First, the Highlight & Animate Condition assured a well-organized, purposeful, scientific investigation at the cost of independent thinking about scientific phenomena. Relieved of the responsibility of structuring an investigation, readers in the Highlight & Animate Condition rarely articulated an idea or question to be investigated that was not explicitly stated in the highlighted prose. Second, participants whose modest knowledge of the topic included naïve or incorrect conceptions were not often disabused of their thinking in the Highlight & Animate Condition. Readers more often - or more effectively - confronted their own incomplete or inaccurate conceptions in the investigations of the Manipulable Graphics Condition.

The preceding discussion highlighted ways in which the Highlight & Animate and Manipulable Graphics Conditions mediated readers' interaction with text. At this point it is appropriate to reflect on the implications for design and instruction that can be drawn from this work. The following discussion of implications was developed in consideration of the interplay among the reader, the text with the experimental features, and the task of learning with science text that were pivotal to the outcomes of this study. Questions to be addressed include: What does this interplay tell us about what upper elementary readers are likely to do under optimal circumstances? What problems are likely to arise under conditions that are less than optimal? And, how might supported electronic environments be designed with an eye to creating optimum learning conditions?

Implications

The discussion of implications is organized around perennial questions in research on supported electronic text, as articulated by Anderson-Inman (2007) and introduced at the end of Chapter 2:

- What are the interactions between texts, resources, and tasks?
- What are effective delivery modes for different resources that support electronic text?
- What are appropriate levels of student control of these resources?

PRODUCTIVE INTERACTIONS BETWEEN TEXTS, RESOURCES, AND TASKS

The interaction between electronic text with supportive resources and the task of making sense of concepts in science was enhanced by the clinical interview setting in which the interactions took place. Of particular interest is the way in which the interactive nature of the interview context prompted self-explanation. Participants in the present study worked with the experimental text while sitting beside an interviewer who shared their view of the computer screen and was generally aware of their knowledge of the ideas represented there. The interviewer was attentive, helpful, and encouraging. The interviewer kept the computer running smoothly, followed along with the reader, supplying difficult words when needed, prompted the reader to use the experimental features, and acknowledged each spontaneous comment in an appreciative manner. Not surprisingly with such an attentive, responsive partner, participants made a number of spontaneous comments as they read. Many of the spontaneous comments were self-generated explanations. Participants produced additional explanations in response to the interviewer's open-ended prompts (e.g., what did you learn?). It is likely that readers used the experimental features more frequently, and studied the ideas of the text with more perseverance than they would have without the interviewer's encouragement.

Self-explanations have been determined to facilitate learning from challenging text. Research shows that readers make inferences about implicitly stated information and understand text deeply in direct proportion to the number of spontaneous or elicited self-explanations that they produce (Chi et al., 1994). Consistent with this research, participants in the present study demonstrated increasingly more complete understanding of ideas that they attempted, repeatedly, to explain. There were several exceptions, however. In fact, the student who demonstrated the least knowledge on outcome measures produced extensive, if incoherent, self-explanations. What distinguished participants who produced few self-explanations from those who produced many? Or whose self-explanations were complete from those that were inadequate? How might we assure that self-explanation, in the context of electronic text, advances understanding?

In this study, participants who produced few, or inadequate, self-explanations were more often those in the Manipulable Graphics Condition. I suggest that they spent too little time with the prose to 1) adopt the structure of the text, which required explanation, 2) review the explanations offered in order to understand them, and/or 3) acquire the language necessary to formulate the explanation. Borrowing from the work of Mayer (2001), I recommend that future iterations of the Manipulable Graphics be narrated. The narration should address each of the potential problem areas noted above, so that readers have an accurate description in scientific language of the phenomena they observed. That is, the narration would accompany each move and model an explanation in user-friendly but scientifically accurate language. It should also reflect the rhetorical structure of the text (e.g., claim + evidence) that signals and effectively communicates the relations of the ideas. I would not recommend (as Mayer does) that graphics be accompanied by minimal prose on the same page. Rather, it would be helpful if readers were redirected to the relevant prose, much as readers were in the Highlight & Animate Condition.

If supported electronic texts are to realize their potential to support classrooms full of readers, they must prompt the reader to engage in strategies such as self-explanation without continual adult encouragement. In fact, the work of Yuill (2007) suggests that adult encouragement may not be necessary. In her *Joke City* work, young peers worked together in a supported electronic environment, developing the metalinguistic skills to explain why increasingly more ambiguous riddles were funny. Participants in Yuill's study engaged in just as much linguistically rich, metalinguistic talk, and more laughter, when they worked in low comprehender-high comprehender pairs, as when they worked in adult-child pairs. In fact, Yuill and colleagues (Kerwalla, Pearce, Yuill, Luckin & Harris, 2008) have developed an interface in which children can collaborate. Using Separate Control of Shared Space (SCOSS) children can each work on a task separately, but on the same screen, representing their own ideas in the process of making joint decisions. In summary, one implication of this work and related research is that collaborative, interactive contexts may prompt the use of strategies that enhance readers' learning from supported electronic text.

EFFECTIVE DELIVERY MODES FOR RESOURCES

The present study provides an example of how resources might be delivered by distributing the intellectual demands of learning with a graphic rich text across the reader and the supported electronic text. Pea (1993) described how intellectual work may be distributed between persons and machines, in a partnership that enables a person to solve complex problems efficiently. With respect to the present study, it is helpful to examine how readers learned with the experimental features in the context a model of six stages in a cyclical system of problem solving that is applicable to learning from text (Pea, 1993, p. 66):

Finding The Problem
Representing The Problem
Planning A Problem Solution
Executing The Plan
Checking The Solution
Reflecting To Consolidate Learning

The problem in the present study was constructing knowledge of the ideas of *How Do We See*. The Highlight & Animate Feature represented the problems, or ideas, explicitly for the reader by: 1) selecting the single-sentence piece of prose that expressed an important idea and 2) animating the graphic in a way that also represented that idea. Note that the reader's role was that of an observer at this point. The Highlight & Animate Feature also offered a plan and initiated its consistent execution. The plan was to segment the text into manageable bites and juxtapose the complementary information available in the verbal and visual representations. It was initiated by means of simultaneous highlighting and animation. At this point the reader needed to assume an active, decision-making role. Consistent with the landscape model of text comprehension (van den Broek et al., 2002), the reader needed to make sense of that information in relation to background knowledge and preceding segments of text, by engaging in comprehension fostering and monitoring processes. Readers who effectively employed such strategies as summarizing, paraphrasing, questioning, and integrating information understood the important ideas of *How Do We See,* though probably without awareness of all of the work of planning and representing that was provided by the supported electronic text.

There were also readers who failed to shift from observer to executor of the plan and evaluator of the solution. For these readers, the way in which tasks were distributed across the readers and the electronic environment did not, at least for an initial reading of the experimental text, enable them to foster and monitor their own comprehension spontaneously.

The Manipulable Graphics provided less explicit representations of the problems, or ideas, than the Highlight & Animate Feature did. The Manipulable Graphics provided readers with multi-paragraph explanatory text and graphics whose component parts could be animated under varying conditions. These constituted the raw materials; readers constructed their own version of the problem, and purpose for their investigation, rather than observe its selection and presentation. Graphics that guided readers to compare and contrast two ideas – the behavior of phenomena under two different conditions or their own common sense conceptions and ideas of the text – provided the raw materials of a plan. Readers with some intuitive knowledge of how to carry out an investigation of multiple variables were able to investigate in an organized way.

In no case was it clear that readers called upon information from the prose to represent the problem or plan an investigation. Some readers approached the graphic as though "gaming" – activating all the elements to see what they could do, producing much activity without clear purpose or deliberate plan with which to investigate the graphic. For these readers, the intelligence that was distributed across the electronic environment was not sufficiently explicit to guide them in using the raw materials to conduct a purposeful investigation.

The description above suggests a number of ways in which intelligence might be distributed differently over the electronic environment and the reader for the experimental text of the present study. The Highlight & Animate Feature allowed readers to take a rather passive role, as it served up prose-graphic combos. A different distribution of cognitive tasks might have the reader take more responsibility for finding and representing the problem, by making choices of which sentence from the prose should be paired with a particular animated sequence. The Manipulable Graphics required the reader to set a purpose and prompted a great deal of activity without a comparable amount of careful consideration. A more equitable distribution of resources would have the electronic text provide an explicit purpose, challenging the reader to develop, execute, and evaluate a plan prove or disprove a proposition from the text. The electronic text might evaluate the readers' investigations, responding by demonstrating a series of moves that the reader did not make, but which were necessary to the conduct of an investigation of the target proposition. In summary, another implication of the present study is that the cognitive demands of learning from text may be distributed across the reader and the electronic resources to enable the reader to assume maximum but manageable responsibility for his or her own learning.

APPROPRIATE LEVELS OF STUDENT CONTROL OF RESOURCES

The present study offered opportunities to consider if readers should decide 1) **if** they will use the supports embedded in an electronic text, 2) **when** they will use the supports, and 3) **how** to use the supports.

Readers' competence to decide **if** they will use the supports embedded in an electronic text depends, in part, on the cognitive and metacognitive processes of reading discussed in Chapter 2 (van den Broek, et al., 2005). Readers must set high standards for coherence and continually evaluate their evolving representation of the text. When their representation fails to meet their standards for coherence they must interrupt their progress through the text to take corrective action. And, they must understand that the actions prompted by the supports of the electronic environment can facilitate learning from text. Use of the experimental features of the supported electronic text of this study was compulsory because it seemed unlikely that participants would choose to use them consistently on their own. One concern was that readers had insufficient knowledge of the complex topic of the text with which to establish appropriately high standards for coherence. Another concern was that the utility of the experimental features would not be readily apparent in this, the participants' first experience with the features. Thus, participants might not choose to use them.

These concerns grew, in part, out of observations of readers using the same experimental features in the earlier Intervention Study of the *Reading to Learn* work. Participants in the Intervention Study engaged in an orientation to the experimental features which included an explanation of their purposes, demonstrations of their use, and opportunities to use the features in reading a short, informational text. This introduction did not assure that participants would use the features. While all of the Intervention Study participants could articulate the purpose of the Highlight & Animate Feature and use it in the context of the orientation, a number of the participants quickly abandoned it when permitted to independently chart their own course through the experimental text. Apparently, they did not see how this feature might add value to their interaction with the text.

Concern about the likelihood that readers will choose to use the resources of supported electronic text is further supported by the literature. For example, Wise and Olsen (1995) provided readers with supported electronic text in which readers could request assistance with word recognition. The investigators compared the number of times 2^{nd}-5^{th} grade struggling readers 'targeted,' or requested assistance with the pronunciation of a word, under two different conditions: 1) days that the reader read independently and so had to monitor his or her own word reading accuracy, and 2) days that an adult sat beside the reader, monitoring word reading accuracy and prompting readers to request assistance for words that were not read correctly. Wise and Olsen found that readers targeted words considerably less often when reading independently. Interpreting Wise and Olsen's finding in light of observations of those in the Intervention Study: struggling readers may not consistently monitor their own reading, or may not realize how the resources of a supported electronic text might facilitate their making sense of text, or may not choose to interrupt their reading to use those resources.

The present study provided evidence that readers should, at least initially, be compelled to use support features in order to develop an appreciation of the utility of those resources. Participants in the present study, who were required to use the Highlight & Animate feature, made statements suggesting that they understood the purpose of this feature and that they depended on it, or the activity that it prompted, to foster their understanding of text. Participants made references to looking for the "importance" – or important ideas to be found in the highlighted sentence – and described how they looked to the graphic when the words were confusing or to the words when the graphic was confusing. Further, they expressed disappointment when reading the (two) pages that did not have a Highlight & Animate Feature. Such comments were not characteristic of participants in the Intervention Study for whom use of the Highlight & Animate Feature was optional, and infrequent.

With respect to **when** to use the supports, the resources of supported electronic text are often time-sensitive. That is, in order to be used to optimum advantage, the resources must be accessed at particular points in readers' interaction with the text. Readers' decisions about when to use the resources are decisions that should be driven by the affordances and purposes of those resources. A primary purpose of the Highlight & Animate Feature and the Manipulable Graphics was to facilitate readers' integration of graphics and prose. In the present study, readers were directed to activate the Highlight & Animate symbols in order, at points where the coordination of ideas in graphics and prose was especially important and opportune. This design decision was based on concern that without experience with what could be gained by the use of this feature and, thus, without a clear sense of the purpose of this feature, readers would fail to use it where optimum for learning.

This concern grew out of observations of the behaviors of readers in the Intervention Study. In the Intervention Study, readers' timing of their use of the Highlight & Animate

Feature seemed to be driven by efficiency, but at odds with the purpose of this feature. Readers who chose to activate the Highlight & Animate symbols usually did not do so as they came to the symbols in their reading of the prose. Rather, they read straight through without pause, sailing over one, two, or three Highlight & Animate symbols that punctuated the prose. Then, when they finished reading all the prose, they went back and activated some or all of the Highlight & Animate symbols. In this way, readers failed to respond in a timely way to cues within the prose to "see figure _." And, they missed opportunities to build understanding of one idea via prose-graphic integration before moving on to add additional nuances to that idea.

By contrast, participants in the study reported here experienced the Highlight & Animate Feature in ways consistent with its purpose. They were required to activate each Highlight & Animate symbol as they came to it. The placement of the symbols had the effect of breaking the text into short, topical segments, allowing readers to build understanding of ideas in stages. Their interactions with the text were characterized, in terms of the moves they made and the ideas they talked about, by frequent toggling between, and integrating of, prose and graphics. Participants made reference to rereading the prose when they were not sure how to interpret the graphic or examining the animated graphic when they were not clear on the message of the prose. Such statements were not typical of participants in the Intervention Study. I conclude that for readers to learn to use the resources of electronic text in ways that facilitate learning, they will initially need guidance to time their use of the resources to suit the purpose of the resources.

In order to use the Highlight & Animate Feature to optimum advantage, readers made two basic decisions: **<u>if</u>** and **<u>when</u>** to activate the resources. These are choices that can easily be built into an electronic text or, in this study, into the interview protocol, for readers who are not yet aware of the value of the resources and their best timing. In the present study, when readers activated the resources at the directed time, a carefully scripted series of well-coordinated prose-and-graphic messages mediated readers' understanding of the important ideas of the text. In contrast, to use the Manipulable Graphics effectively, readers had to make more complex decisions with respect to **<u>how</u>**

the resources should be used to best enhance their learning from text. Readers were expected to use the Manipulable Graphics to conduct an investigation of scientific phenomena. Using terms introduced in Chapter 2, efficacious use of the Manipulable Graphics required that readers have a clear conceptual purpose for their investigation, that is, an understanding that they were constructing *substantive knowledge* (Schwab, 1994) of scientific phenomena. And readers needed inquiry-based reasoning processes, or *knowledge of syntactic structures* (Schwab, 1994), to generate and interpret the evidence needed to test claims about substantive knowledge.

Evidence from the present study suggests that the Manipulable Graphics Condition failed to supply readers with an explicit conceptual purpose with respect to the knowledge to be constructed. Rather, the *Directions to Investigate* guided readers in the procedures to be used to manipulate the graphics (e.g., move the book, click on the light source). Nor did the *Directions* provide implicit models of syntactic knowledge, or investigatory practices, in ways that allowed readers to infer the purpose of the investigation. For example, readers were not directed to employ a practice such as holding one variable constant (e.g., position of the book) while observing changes in one other (e.g., effects of different sources of light striking book at different points). Some participants lacked the syntactic knowledge of science needed to guide their investigation of the graphics. Consequently, in their descriptions of what they observed and learned from their investigations, a number of readers focused exclusively on the procedural aspects of the investigation. Without explicit links between the prose and the graphics, readers did not review the prose nor identify specific, important ideas to be investigated. When they did not gain much understanding from the investigation, readers seemed frustrated, but unsure of how to remedy the situation.

To summarize, when learning from text calls for an investigation like that of the present study, the supportive resources should guide readers through the process of investigation, gradually releasing responsibility as readers demonstrate that they can set a purpose and construct an investigation. A sense of purpose and the means to carry out that purpose are more critical to learning than a sense of control over how to use resources.

Limitations

The results and implications of this study must be interpreted in view of several limitations to be found in its design, including the choices of participants, measures, and materials. Since the fine-grained analyses of readers' interactions with the experimental text demanded considerable time, enrollment in the study was restricted to a just twenty participants. It was important to know these participants as well as possible, since upper elementary students have rarely been studied in contexts such as the research presented here. What we have learned from this small sample of fifth grade struggling readers can provide insight into, but cannot be considered typical or even representative of, other upper elementary struggling readers. Also, the small sample size prohibited analyzing readers' responses by condition across particular reader characteristics that might prove to be important, such as metarepresentational or language skills or gender.

The study employed only one experimental text concerning one topic in the physical sciences: light and vision. The topic was appropriate with respect to curricular standards for fifth grade and the design of the text reflected the collaboration of experts: a scientist, graphic designers and literacy researchers. However, domain-specific considerations must be taken into account in adapting texts from other domains to a comparable digital environment. We cannot presume that readers would respond to another text, particularly one from another subject area, as they did to the experimental text. Though, given the consistency of readers' responses to different pages within a condition, we should be alert to the possibility that readers' initial experience with the digital environment might shape future interactions with texts in the same environment.

The measures of knowledge gained and knowledge articulated provided somewhat incomplete profiles of reader learning. The measure of 'knowledge gained' sampled only a portion of the important ideas of the experimental science text. It used multiple-choice questions of quite variable difficulty – some required interpreting complex sentences; others required recognizing a graphic from the text. The interview that elicited 'knowledge articulated' sampled the readers' ideas with open-ended questions, but provided no direction to address a specific idea. Ideally, the measures would have provided a more complete profile of reader knowledge. Supplemental constructed response questions could ask readers to draw and/or explain important concepts that they had not addressed spontaneously or satisfactorily by means of the other measures.

The protocols for data collection did not allow interviewers to determine what it would take for a reader who was not using the environment optimally to do so. Because data was collected by several interviewers, these interactions were strictly scripted. That is, they asked only the agreed-upon open-ended questions; they did not ask any additional questions about readers' understanding of specific ideas. In retrospect, it would have probably enhanced our understanding of how readers were learning from the text to (1) ask participants about their understanding of important ideas that they did not address spontaneously, and (2) provide participants with as much scaffolding as needed to realize and articulate the important ideas in the course of their investigations. It should also be noted that the presence of the interviewer was, no doubt, a factor in encouraging children to work with the text.

Future Research

We have just begun to exploit the potential of digital environments to support struggling readers to learn from graphic-rich, informational text. The opportunities to offer supported electronic text to struggling readers becomes ever more feasible with advances in technology and applications of that technology to research on learning from text, as well as advances in policy. For example, the National Instructional Materials Accessibility policy guarantees that newly published textbooks will be available in digitized form and thus, adaptable to use in supported electronic reading environments. Future research might address the following questions:

What, in the long term, would be the purpose of an electronic environment with features such as the Manipulable Graphics and the Highlight & Animate Features?

Would it be primarily to develop deep understanding of a number of important concepts in a particular text or domain? Examples of electronic environments like this can be found in the work of Reiber (1990b), Quintana, C., Chang, H., & Krajcik, (2007), and the present study. In such cases the electronic environment would be custom built to the text as it was for *How Do We See* in the present study. It would do the work of supplying domain-specific intelligence about domain-specific principles and processes (e.g., which specific segment of text to coordinate with its graphic representation) with which the reader was unfamiliar. A number of modifications to the experimental features would be recommended to make them more suited to designers' expectations of them. While the resources of the electronic text would initially do a significant amount of the intellectual work, responsibility for these activities would be gradually shifted to the reader where desirable. The trade off, of course, is that only a relatively few such texts could be developed. It took a tremendous expenditure of resources – time, money, and cognitive energy – to build the supported electronic environment with *How Do We See*.

There is another possibility. Another long-term purpose for developing supported electronic environments with features such as the Manipulable Graphics and the Highlight & Animate Feature would be primarily to develop strategies for approaching graphic-rich texts. In this scenario, the electronic environment would provide guided learning opportunities to use resources of electronic text, within and across domains. Examples of such environments can be found in the work of others (Caccamise, et al., 2007; Dalton & Proctor, 2007; Johnson-Glenberg, 2007; McNamara, et al., 2007; Meyer & Wijekumar, 2007) who have designed supported electronic texts to deliver classroom-based interventions that support learning from text.

Particularly appealing is the intervention of Meyer and Wijekumar (2007), the Intelligent Tutoring of the Structure Strategy (ITSS). This model of intervention is based on a careful analysis of steps that readers can take to identify structural characteristics of text and use those to organize understanding and recall of information. To build from the present study, the structural characteristic of interest might be complementary, scientific prose and graphics. The steps to be modeled might include identifying important ideas, locating representations of those ideas in graphics, mentally animating the graphics, and integrating those ideas. In ITSS the steps are modeled by an 'agent' and then practiced by readers in response to prompts which are gradually faded. ITSS also provides feedback on readers practice activities. A host of questions need to be explored in additional research. What would be an optimal breakdown of steps in the integration of prose and graphics? What are effective methods of teaching these steps (e.g., certainly the design of agents is not well-researched at this time). Consistent with Meyer and Wijekumar's model, it would probably be practical to develop the instructional steps using little or no technology and determine the points at which it makes sense to distribute intelligence across an electronic environment for the most efficient instruction and the most purposeful practice activities.

How can we improve the Highlight & Animate Feature and Manipulable Graphics, so that they accomplish their purposes more effectively, or for more readers?

A design experiment might begin with the digital environment as it is and introduce a series of modifications or scaffolds until the reader succeeds in using the environment to learn. These modifications might draw on the best of each of the two features. For example, drawing on the way in which the Highlight & Animate Feature presented prose; the prose that accompanies the Manipulable Graphics feature might be broken into more manageable 'bites' with prompts at intermittent stopping points to investigate the diagram. The modifications might include explicit instructions or models of scientific practices (including language) that readers did not use spontaneously. So, the Manipulable Graphics feature might be designed with 'directions to investigate' that guide readers in using the prose to set a purpose, organize, and/or describe their inquiry. Or, the actions that the readers took on the diagram could be labeled within the diagram in print or they could be narrated.

How can the support features and readers' paths through digital text be customized so as to support them adequately and still use their time and resources efficiently?

In light of the variability to be found in the reading practices of struggling readers, the modifications described above might be incorporated into a digital reading environment as a 'menu' of items that can be delivered to readers as required. In design experiments, as described above, we could discover the modifications needed and the most efficacious presentation of those elements for individual readers. Readers' pretests of knowledge of the topic, or knowledge of strategies to support learning from text, or familiarity with the resources of the digital environment might be used to guide the choice of which resources would be required and which would be optional. It may be possible to employ "intelligent agents" as a means of customizing prompts from the text in response to the moves that each reader makes. In addition, agents may facilitate readers' learning from text by serving as social and intellectual partners in knowledge construction.

How can we discover if, what, and how readers are learning from these digital environments?

In future research, measures of readers' learning might include constructed responses such as drawing their own representation of a concept from the text and explaining it verbally or in writing. Readers' descriptions of their own representation may provide some insight into the processes in which they engaged to make sense of the text. These constructed responses could supplement other products of reading such as multiple-choice measures of comprehension of concepts.

What new features might be created to make the digital environment even more conducive to learning from graphic-rich informational text?

The work reported here showed that a digital environment can prompt interactions with text, such as the integration of graphics and prose, which lead to comprehension of complex concepts. Additional tools could prompt other productive interactions with text. For example, the digital environment could offer a 'Diagram Construction' feature. This feature would provide the raw materials for readers to construct their own graphics and/or animate them. Such a feature might foster readers' metarepresentational skills as they create concrete images of what they read in preparation for constructing mental representations from other texts.

How could the learning gains realized by some struggling readers in a particular digital environment be extended to other content areas or to static texts?

School-aged readers encounter an abundance of graphic-rich text in both digital environments, such as the World Wide Web, and static texts. Thus, it is important to discover if and how the domain-specific skills (e.g., structuring an investigation of scientific phenomena) and domain general strategies (e.g., integrating prose with graphics) prompted in one digital text might be transferred to a digital text in another domain or to a static text. A related question would be how to scale-up the experimental digital environment by teaching teachers to anticipate challenges and misconceptions in texts and create graphics that would support readers to understand the challenging concepts and confront their own misconceptions.

Other empirical questions remain. Can the reader profit from working in an electronic environment without adult guidance, allowing the intervention to be classroom based rather than individual? In the absence of an adult, how can the reader respond to the text and get feedback on those responses? Can careful study of a small set of graphic rich science texts in a supported electronic environment enable the reader to generalize his or her experience to learn from other graphic-rich science text?

I began this account of my dissertation study with the story of one struggling reader's highly successful use of the experimental digital environment to learn from challenging science text. In the course of my work on this manuscript I have often thought of Jack. I do so now with a sense of urgency. Jack would be in middle school and encountering a lot of challenging text. I wonder how he makes sense of it all. I am encouraged by recently published reports of research that utilizes innovative technologies to support readers' comprehension of middle school and high school texts. More and more it seems possible that if we can imagine a powerful and flexible intervention, we can harness the power of technology to deliver it. Won't Jack be glad to see that!

Appendices

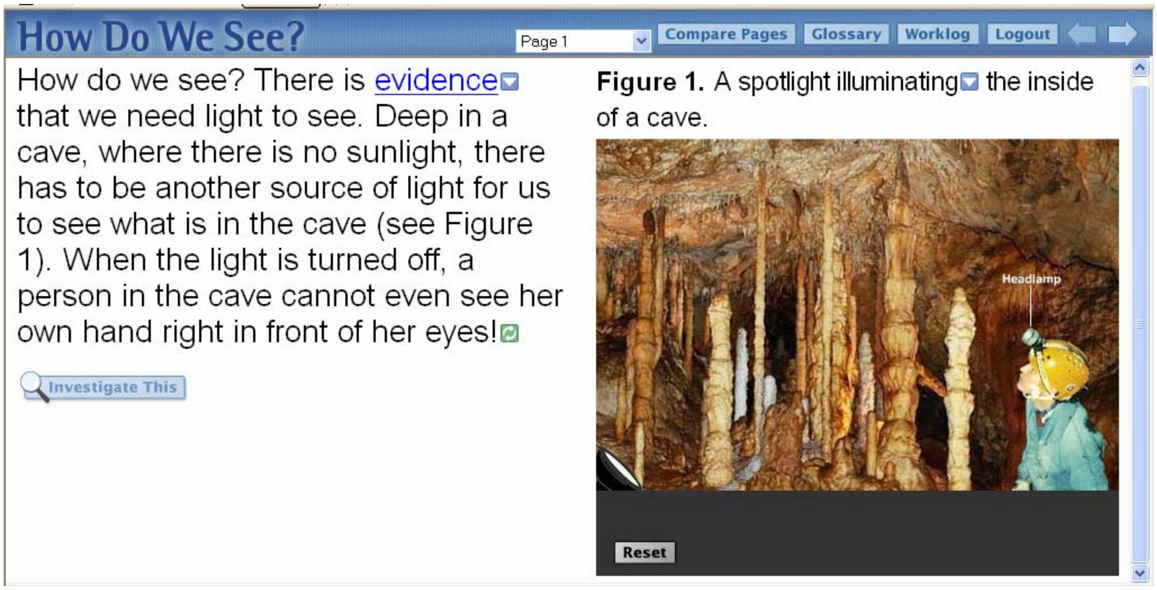
Appendix A: Affordances of the Highlight & Animate Feature and Manipulable Graphics

Page 1 of *How Do We See*

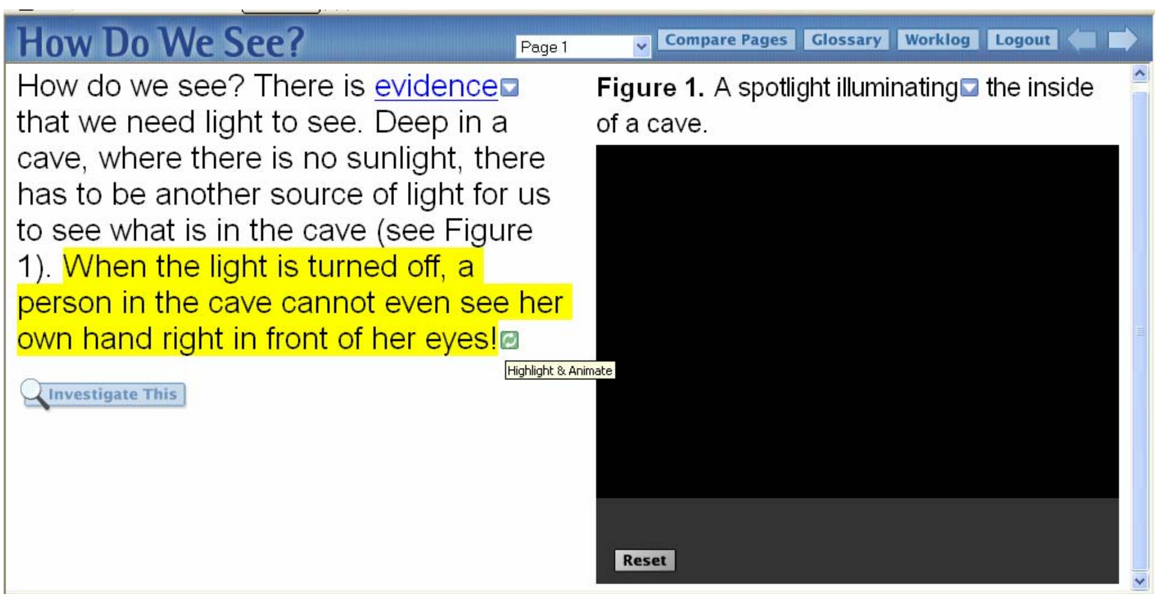
Important idea: We need light to see; without light we cannot see

Highlight & Animate Condition Affordances:

The Highlight & Animate feature prompted the reader to contrast what a person could see in a cave with light…

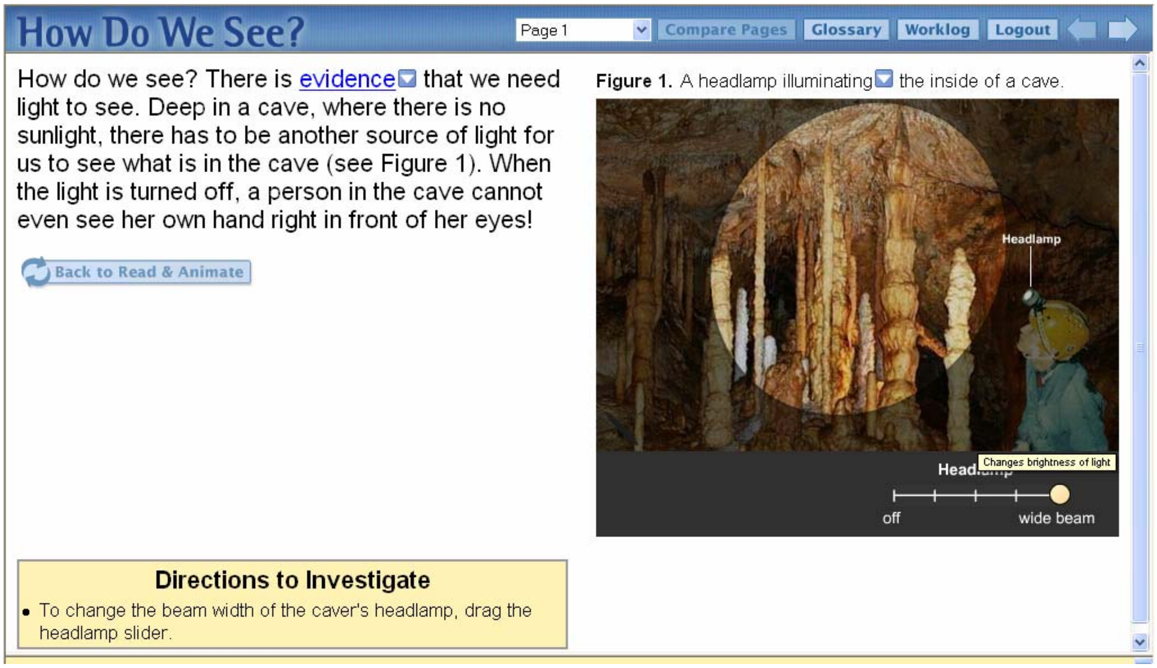


…and without any light (in the highlighted prose): she "cannot even see her own hand…"

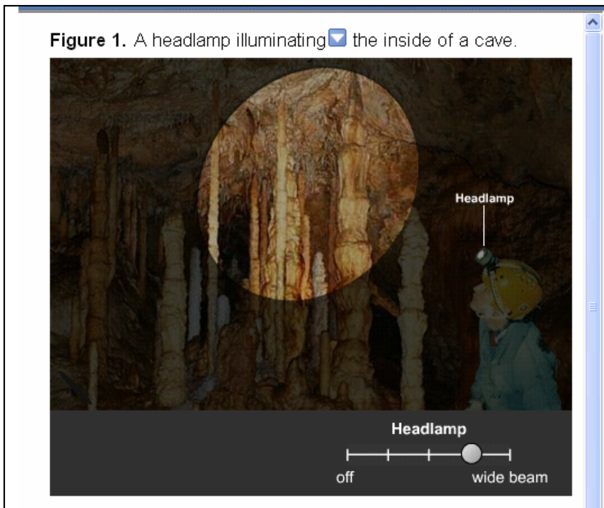
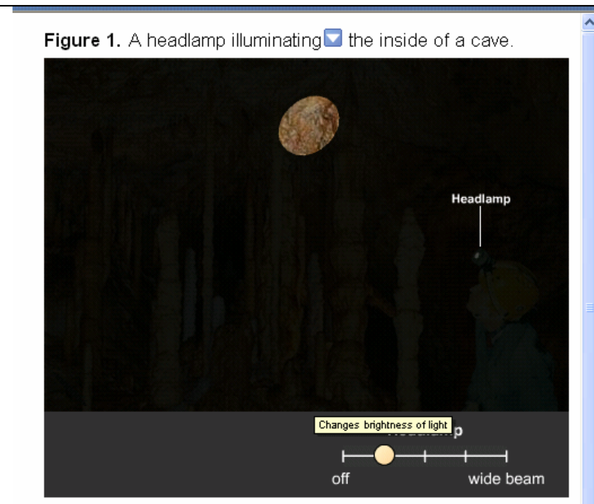


Manipulable Graphics Condition Affordances:

The Manipulable Graphics enabled the reader contrast what a person would see if he had more…



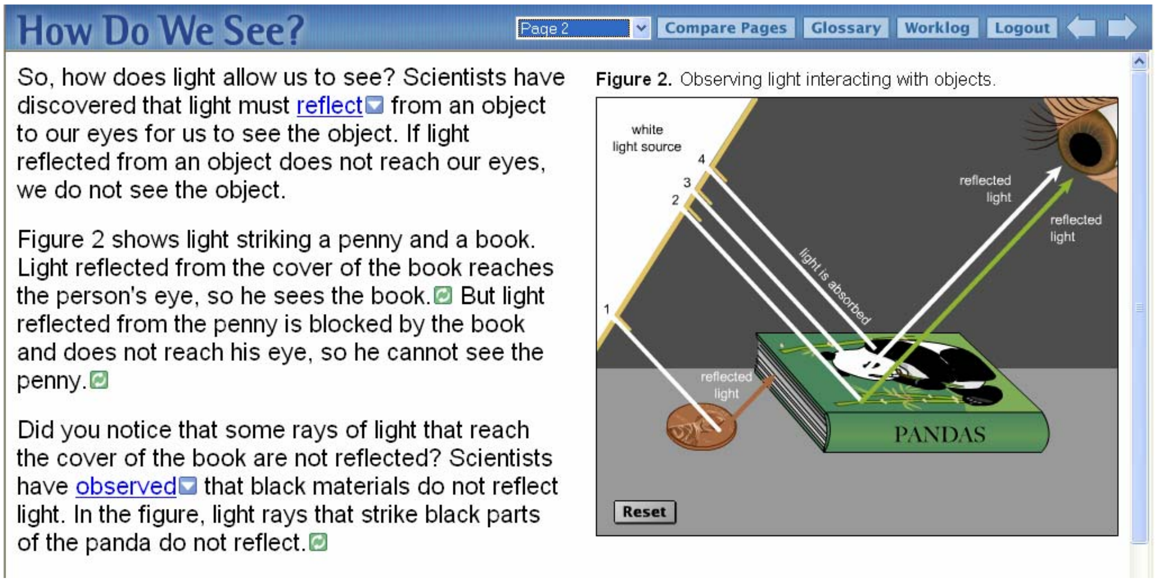
…or gradually less light with which to explore a cave. The reader moved the slider to the left/right in steps until the light was fully off/ on and the cave was completely dark/light.

	
Slider moved one increment to the left.	Slider moved three increments to the left.

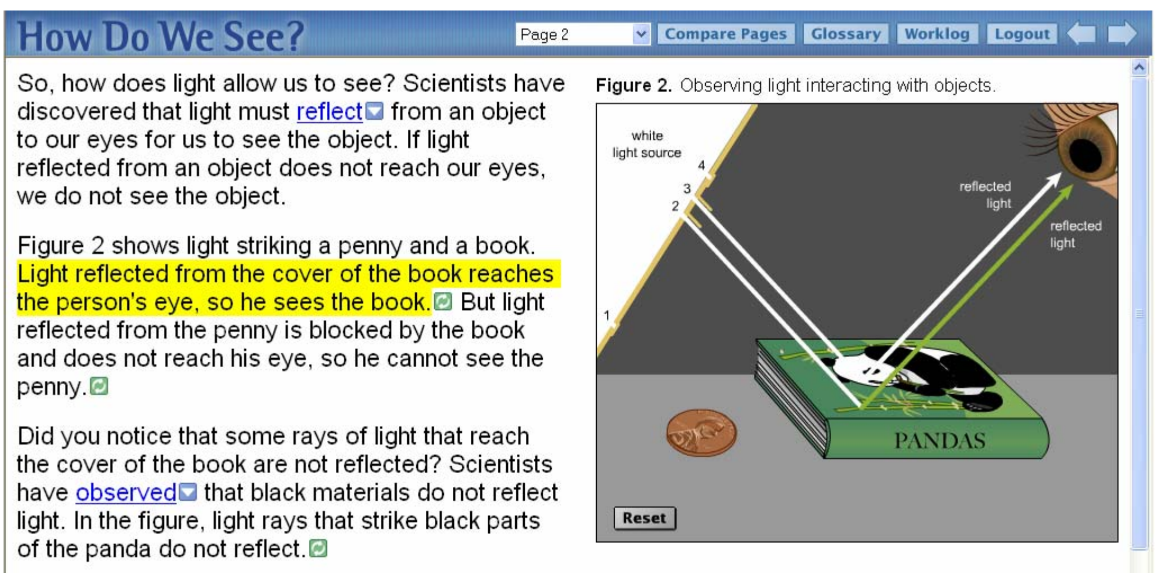
Important ideas: Light reflected from an object enables us to see the object; When light reflected from an object is blocked, we cannot see the object; Light is not reflected from materials that are black

Highlight & Animate Condition Affordances:

The Highlight & Animate feature guided the reader to find within this figure,…

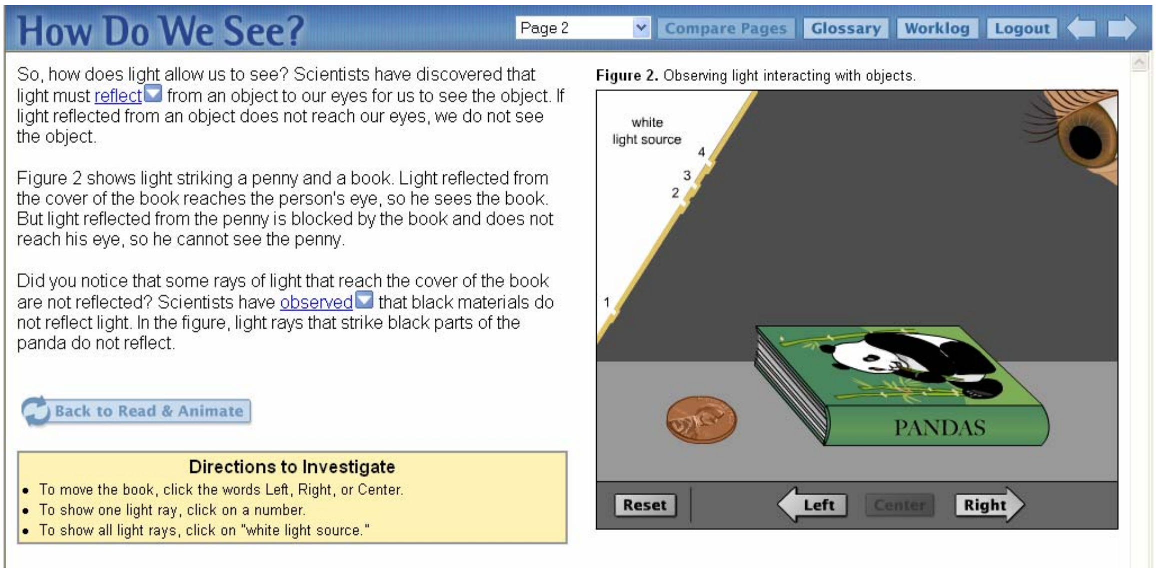


…and contrast, examples of light reflecting, or not, and a person seeing, or not, depending on the surface it struck. The prose explained why the light reflected, or not.

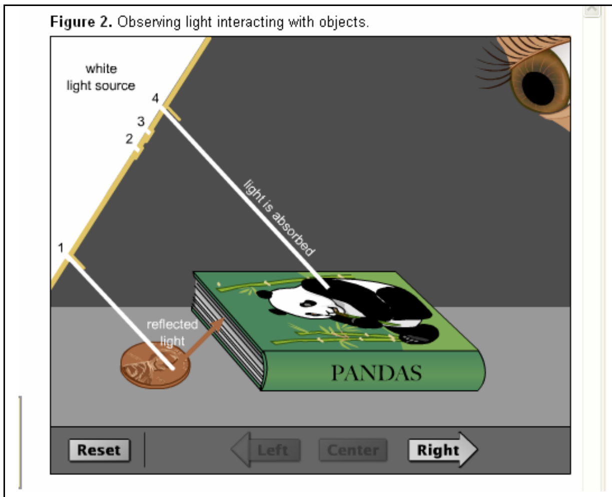
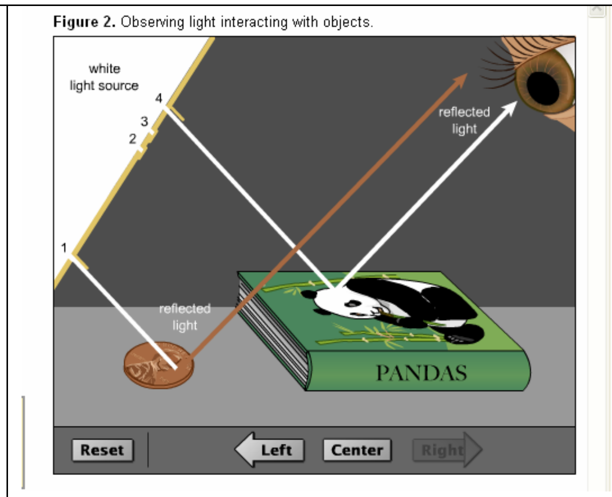


Manipulable Graphics Condition Affordances:

The Manipulable Graphics provided readers with raw materials – light sources, objects for lights to strike, and a person's eye to (potentially) see the object – with which to construct or test their ideas about how we see when light reflects from an object.



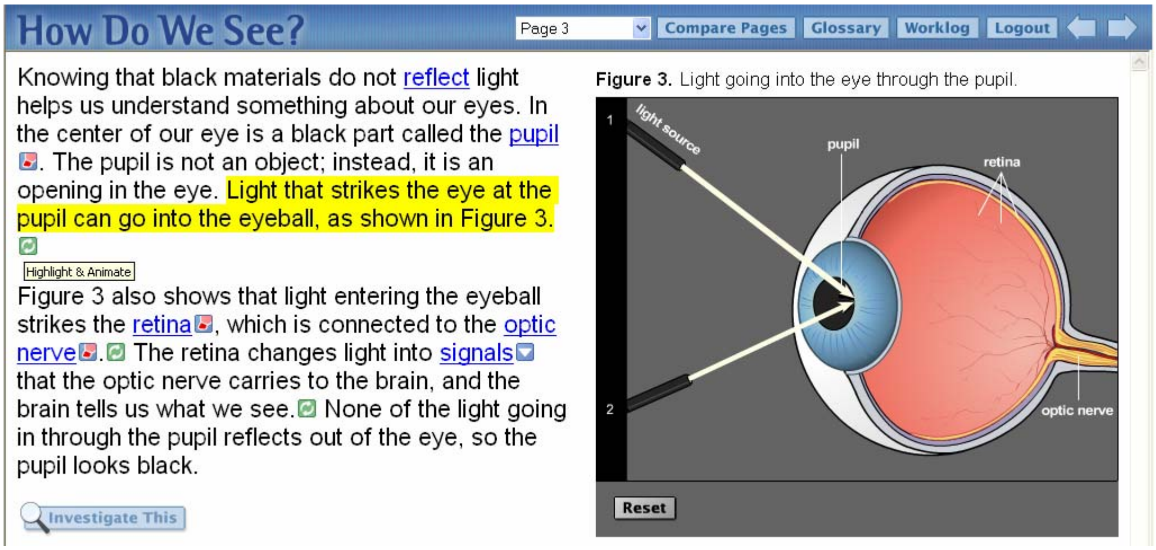
Readers had the options to change the position of the book and choose one or more or all light sources to activate, in their investigation.

	
The book was moved to the left. Light that struck the penny was blocked by the book. Light from sources 4 struck the black arm and did not reflect.	The book was moved to the right. Light that struck the penny was not blocked, so it did reflect. Light from source 4 struck the white face and did reflect.

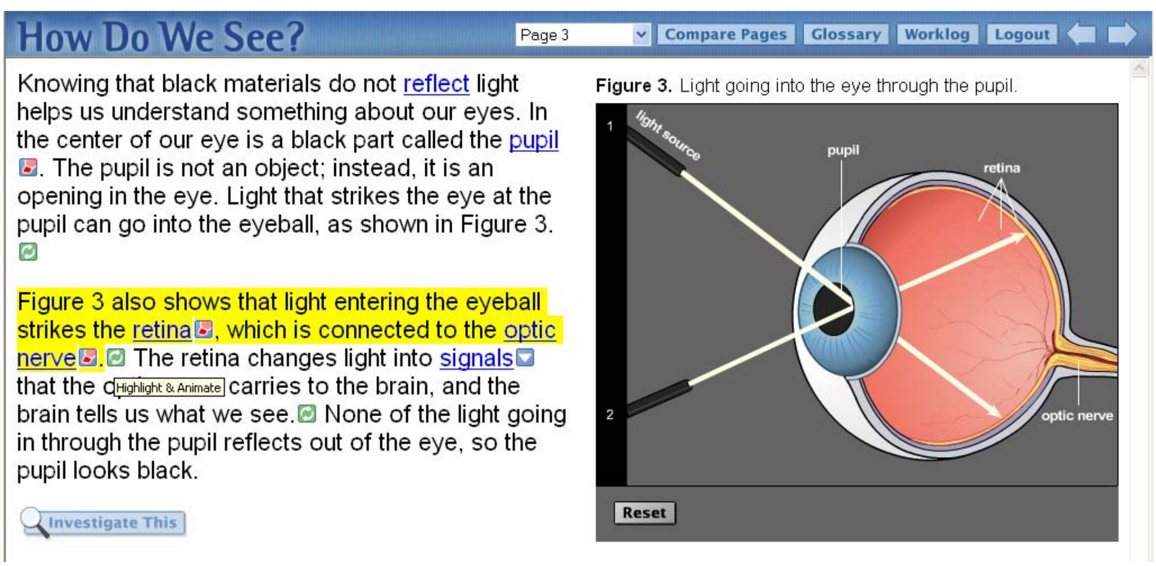
Important ideas: Light enables us to see when it enters the pupil; Light interacts with structures of the eye – the retina and optic nerve; The brain interprets signals from the light to tell us what we see.

Highlight & Animate Condition Affordances:

The Highlight & Animate feature directed readers to the part of the eye that admits light

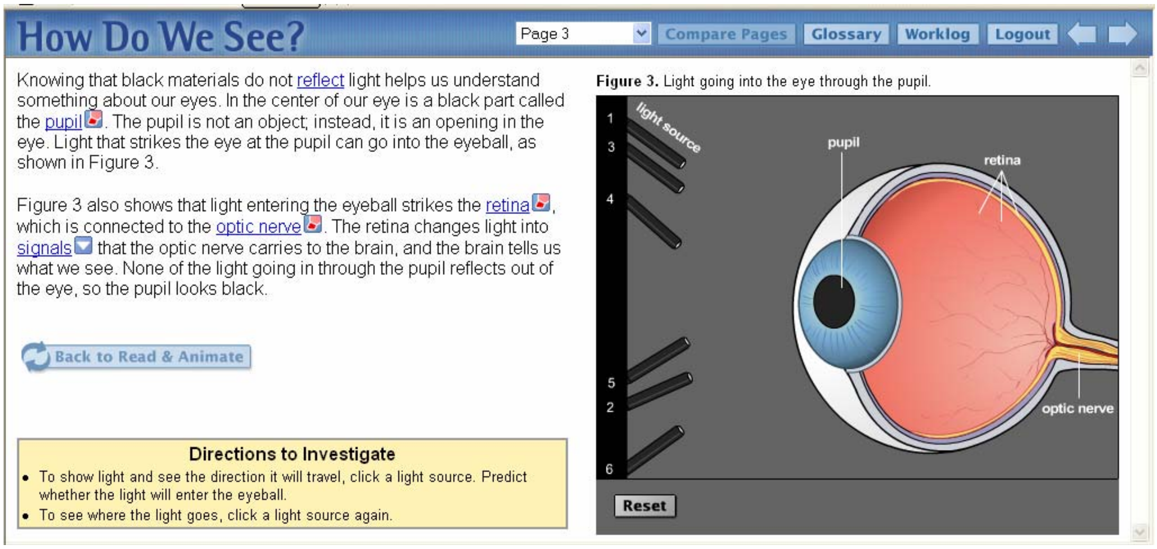


…and then to the other structures with which light interacts. When light struck the retina, a tiny, bright light (the message) traveled from the retina to and through the optic nerve.

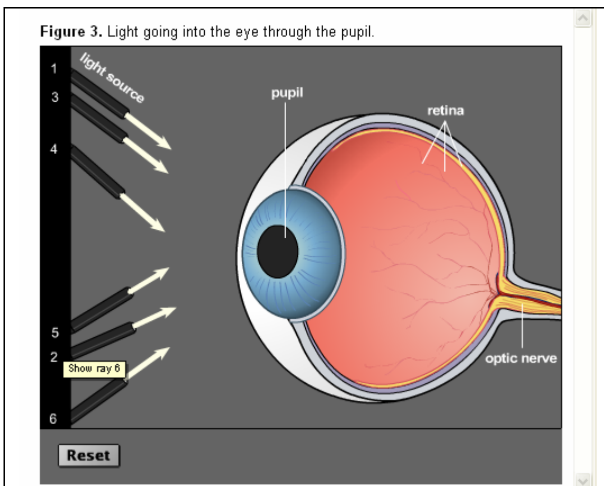


Manipulable Graphics Condition Affordances:

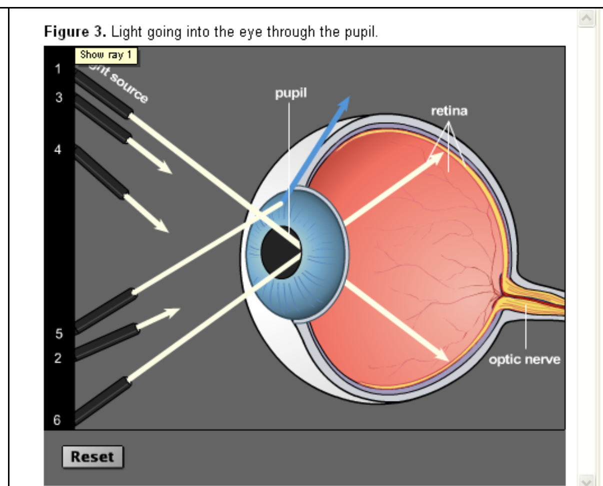
The Manipulable Graphics let readers choose the source of light and direct it toward the eye in a two-step process …



… that provided an opportunity to (1) predict if light would intersect with the pupil and (2) test that prediction. When light struck the retina, a tiny, bright light (the message) traveled to and through the optic nerve.



Step 1



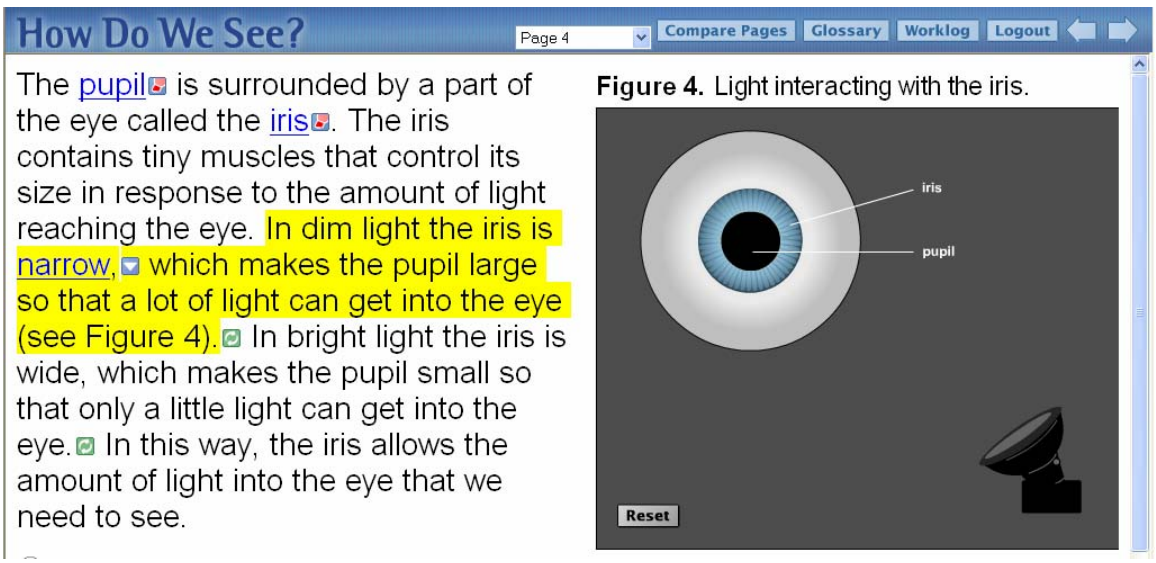
Step 2

Important ideas: The iris regulates the amount of light that enters the eye through the pupil;

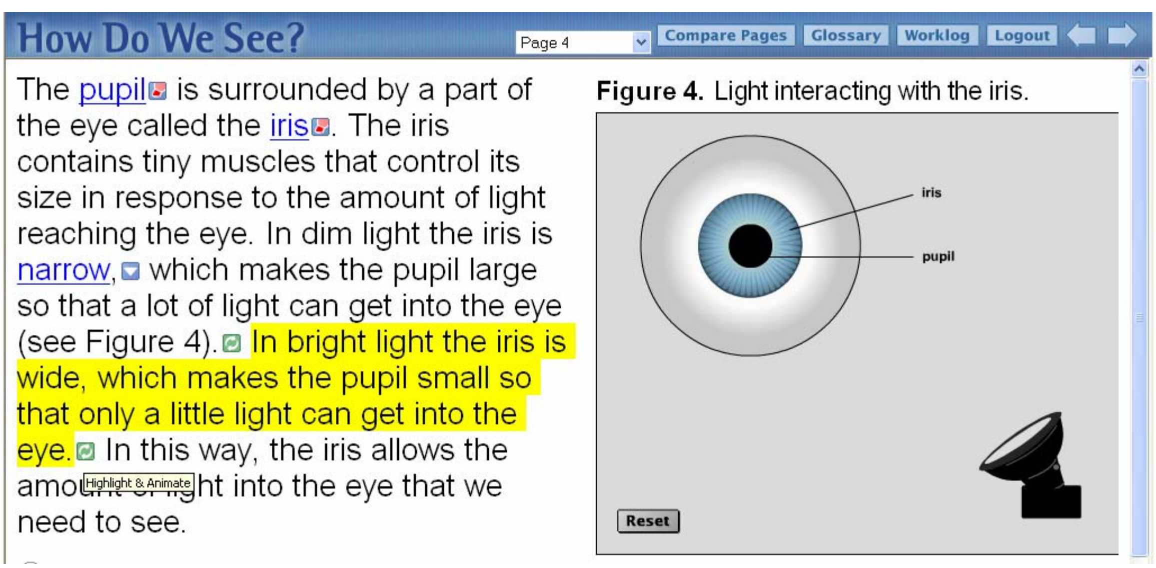
The pupil admits more light in dim conditions, less light in bright conditions

Highlight & Animate Condition Affordances:

The Highlight & Animate feature directed the reader to the contrast in the relative sizes of the iris and pupil under conditions of dim light…

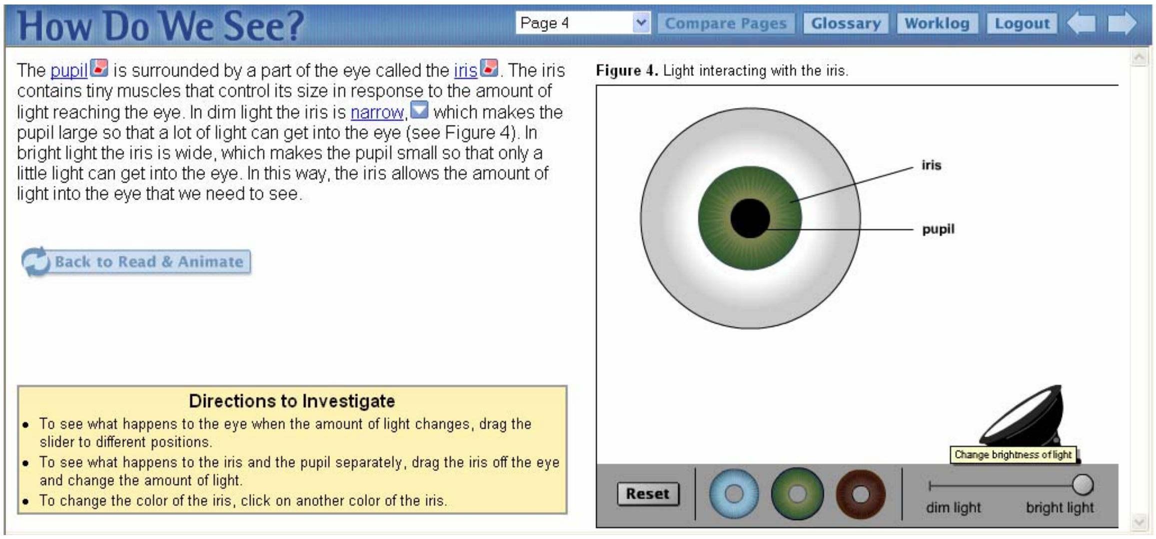


…and bright light. The prose stated the iris controlled how much light the pupil admitted.

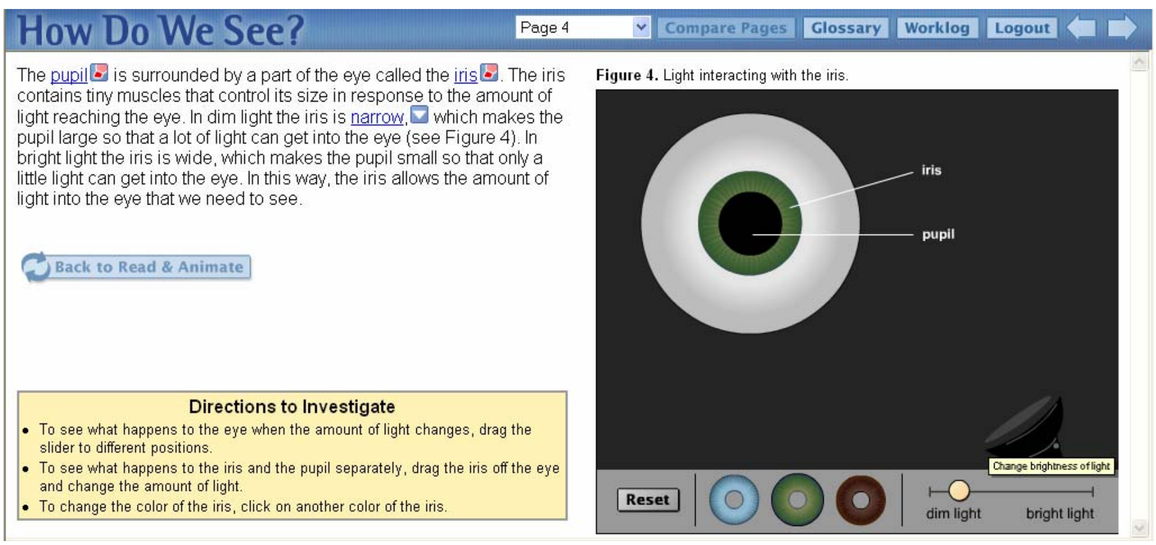


Manipulable Graphics Condition Affordances:

The Manipulable Graphics allowed the reader to personalize the investigation by changing the color of the iris…

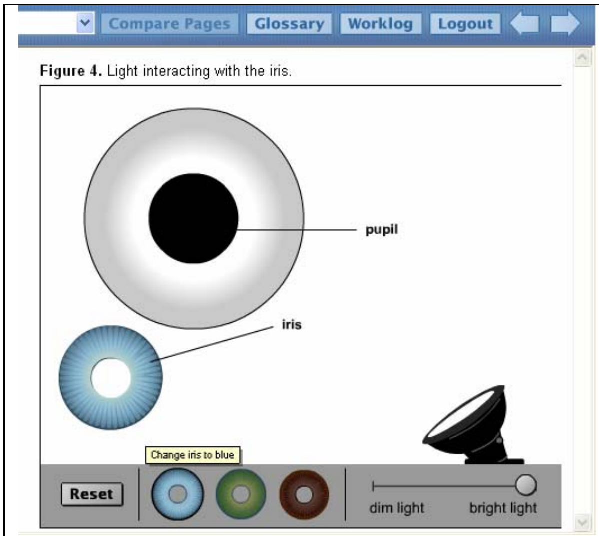


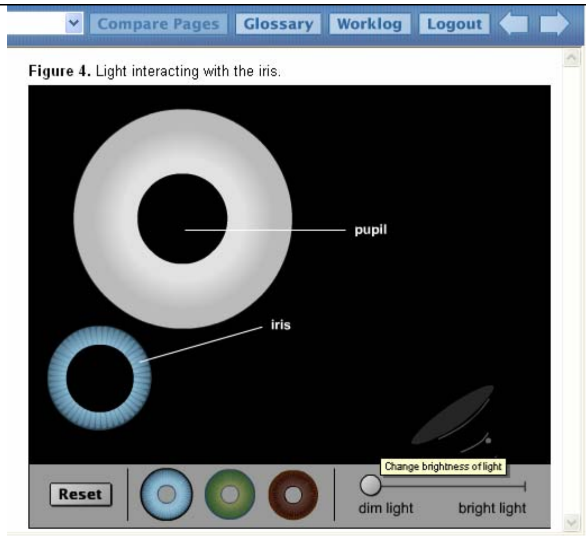
…and to observe changes in the appearance of the iris and pupil when they used the slider to change the amount of light shining on the eye from bright to dim to bright…



Manipulable Graphics Condition Affordances (continued)

…as well as to observe the change in the size of the iris and the lack of change in the size of the pupil under conditions of dim and bright light.

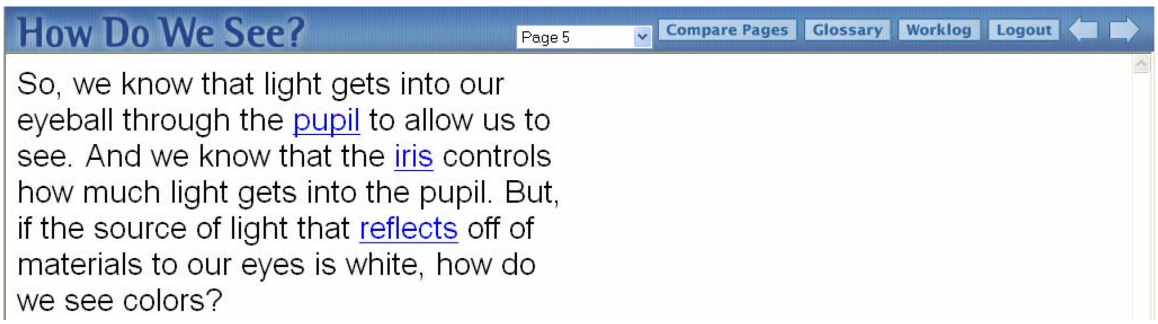




The iris is wider in bright light, narrower in dim light. The pupil is the same size under both conditions.

Page 5 of *How Do We See*

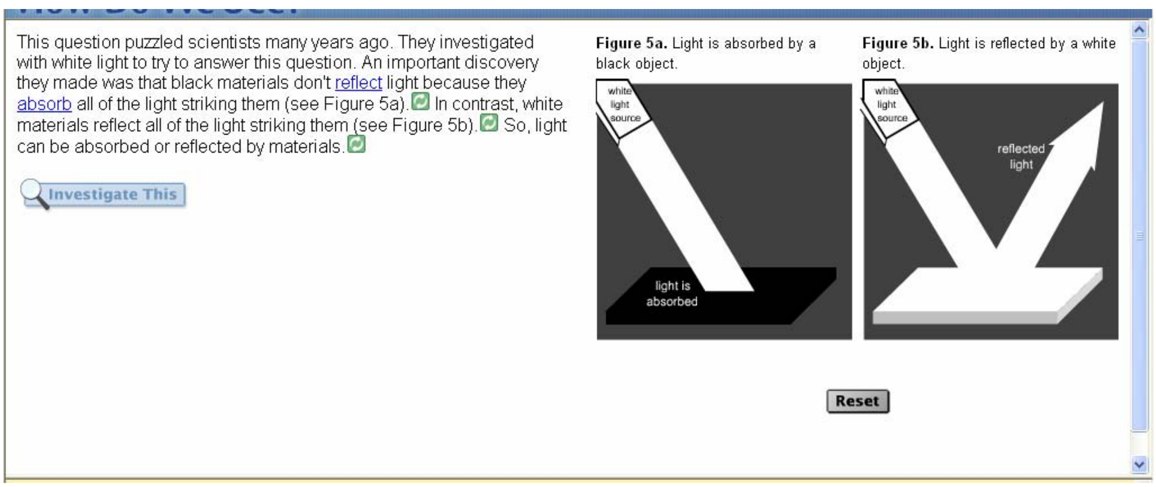
Page 5 was exactly the same in both the Highlight & Animate and the Manipulable Graphics Conditions. It came at the midpoint of the text and provided a brief review of important ideas from the previous pages. It also posed a question to guide the readers' transition to upcoming important ideas. There was only glossary support and text-to-speech on this page, no Highlight & Animate feature, nor Manipulable Graphics.



Important Ideas: Light is absorbed or reflected by materials in proportion to its depth of color. Black materials absorb light; white materials reflect light.

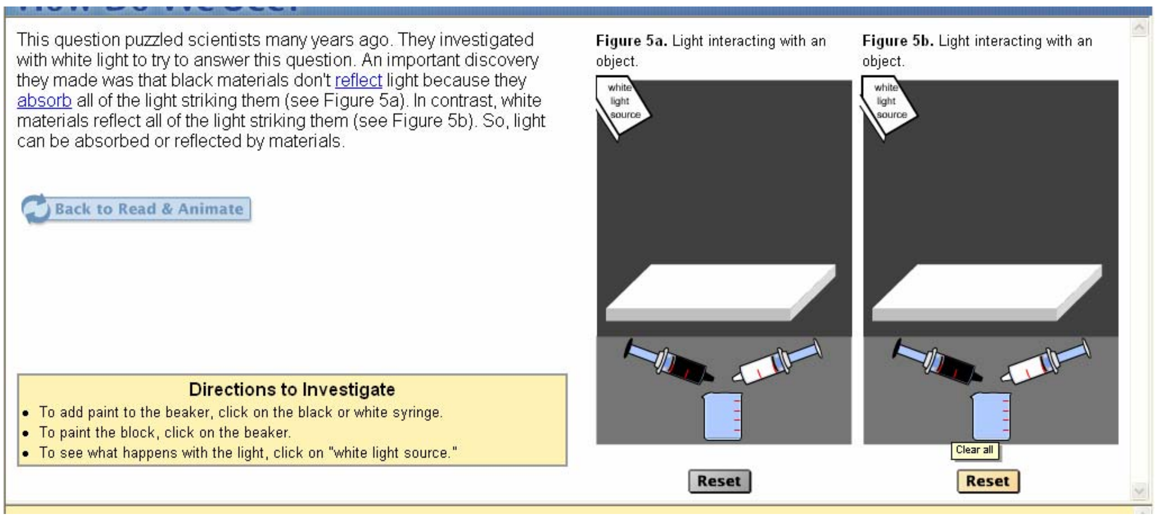
Highlight & Animate Condition Affordances:

The Highlight & Animate feature presented the contrasting effects of light striking black and white surfaces. When they clicked on the 'white light source' in Figure 5a, light traveled to the black surface and stopped/was absorbed. When they clicked on the white light source in Figure 5b, they saw light travel to the white surface and then reflect.

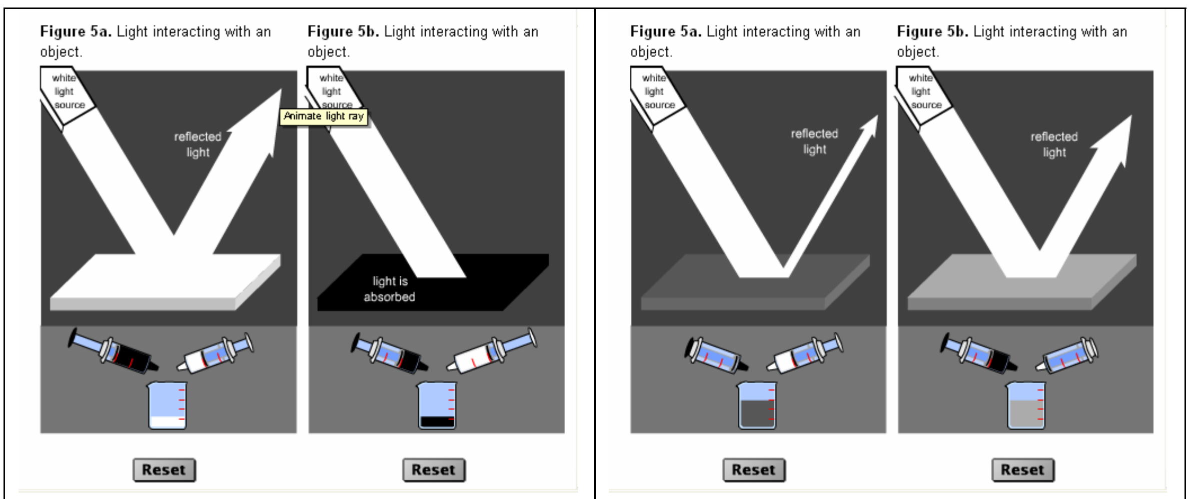


Manipulable Graphics Condition Affordances:

The Manipulable Graphics offered an opportunity to compare the effects of light striking two adjacent surfaces. They painted each surface with paint that they prepared by squirting paint from the syringes into the beakers. Depending on how they chose to mix it, the paint might be white, black, or dark, medium, or light gray.



Light was reflected from, or absorbed by, these surfaces in different amounts, in proportion to the depth of color of the surfaces.



Readers colored one block with only white paint	And the other block with only black paint	Readers mixed all black and some white to paint one surface dark gray	And mixed some black and all white to paint another surface light gray

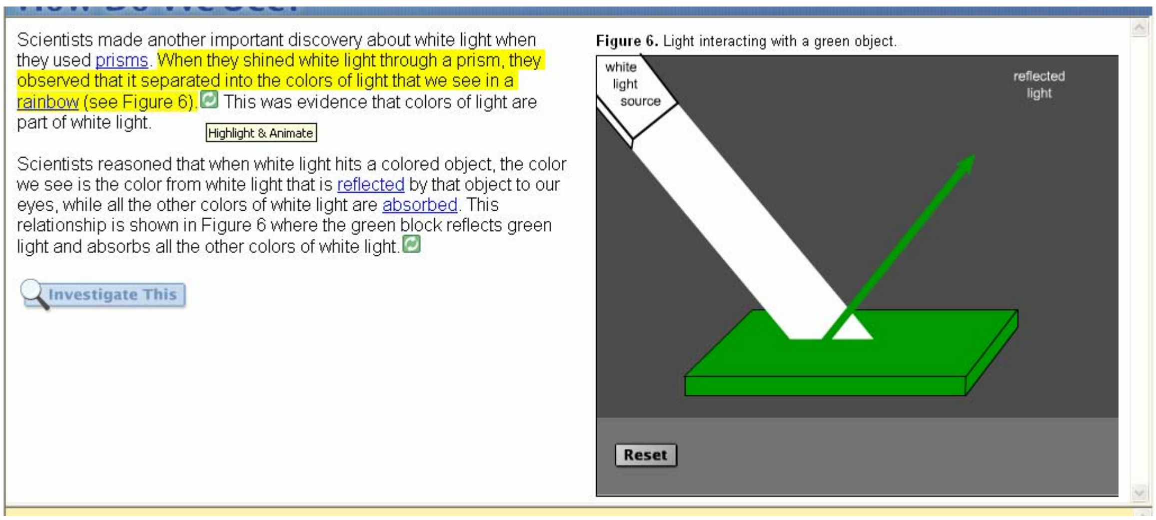
Page 7 of *How Do We See*

Important Ideas: Light is composed of colors;

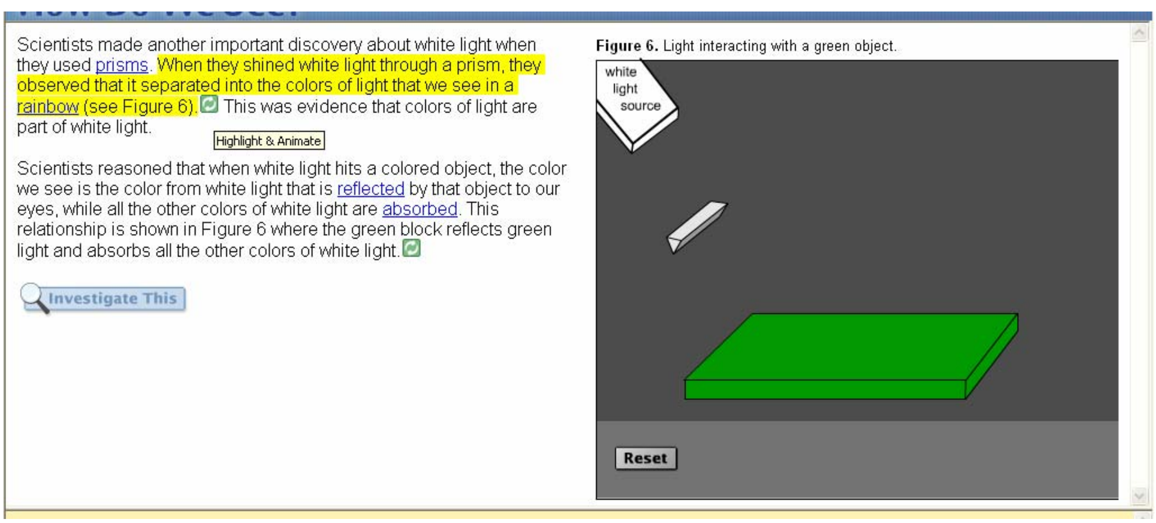
We see the color of light reflected from object; other colors of light are absorbed.

Highlight & Animate Affordances:

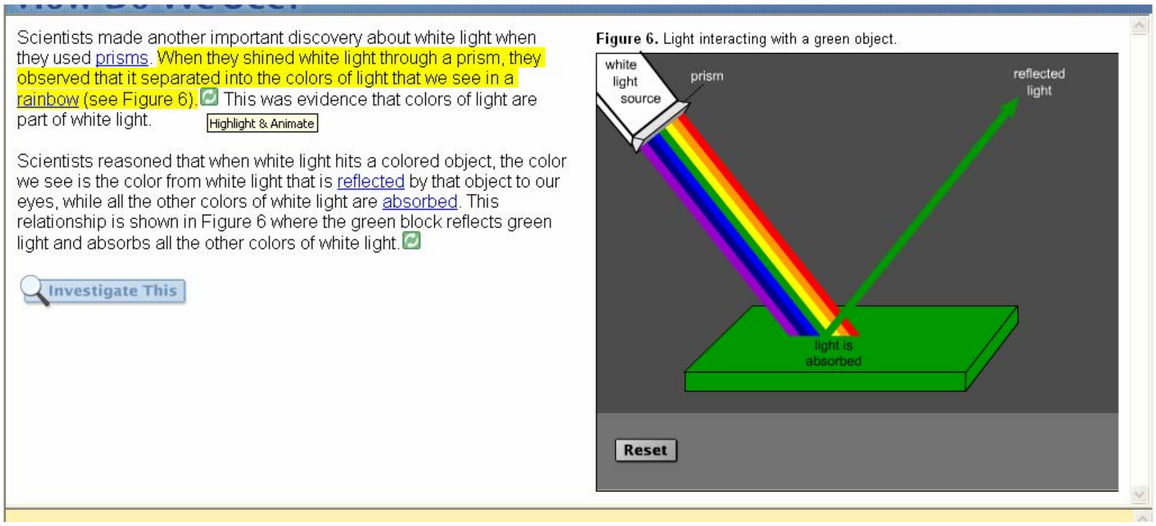
The Highlight & Animate feature provided a three-step sequence depicting the contrast in form and similarity in function between white light and the colors contained within white light. First, white light struck a green object and green light reflected.



Then, a prism appeared near the opening of the white light source.

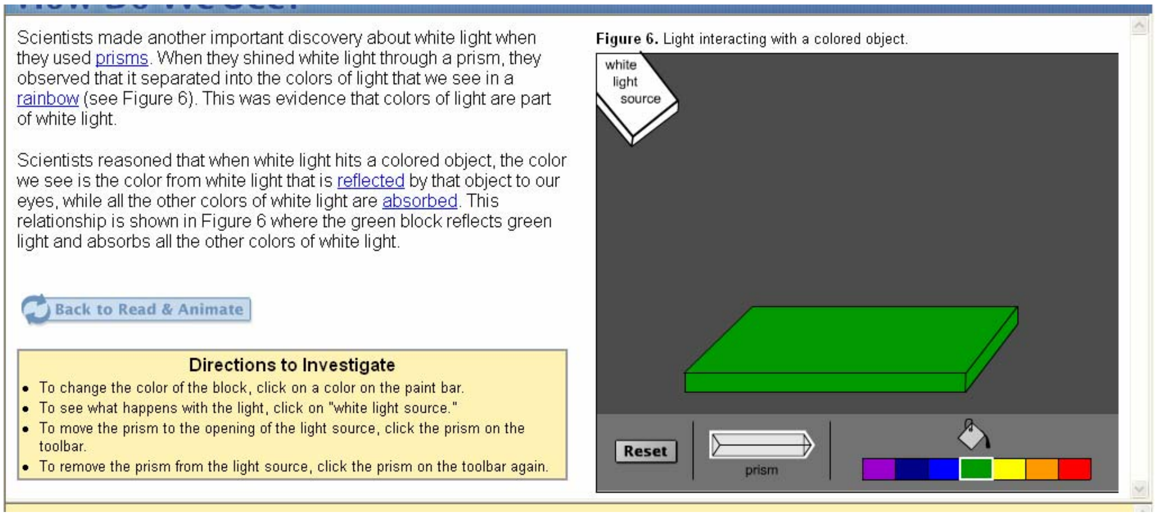


Finally, white light directed through the prism revealed the colors contained within the white light. Still, green light reflected from the object.



Manipulable Graphics Condition Affordances:

The Manipulable Graphics provided the same materials – green block, white light source, and prism – as the in the Highlight & Animate feature, as well as…



…colors with which readers could change the surface of the block. So, readers could make white light strike any color object and see the same color of light reflect from the object (Figure 6a). They could send a prism to cover the opening of the white light source, and reveal the colors contained within the white light (Figure 6b).

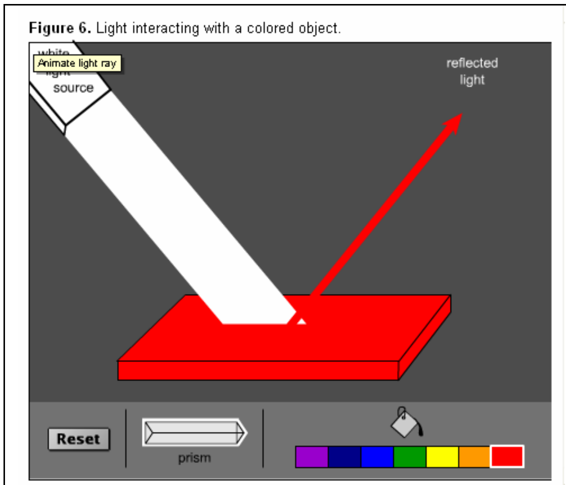


Figure 6a

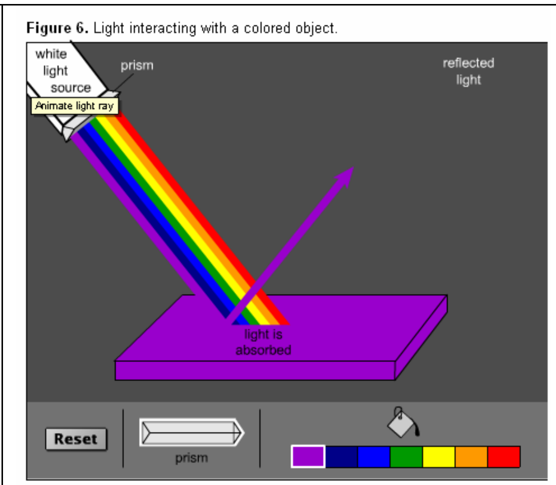
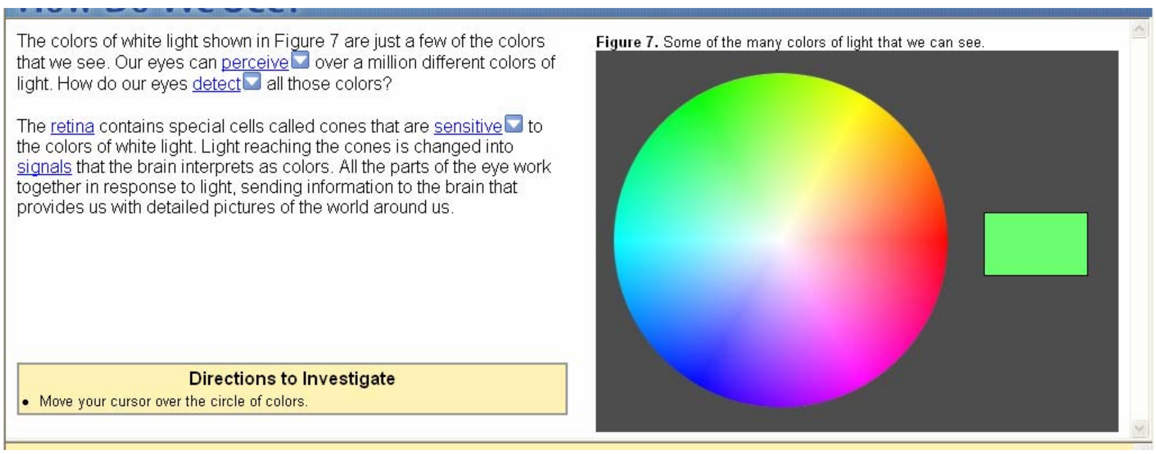


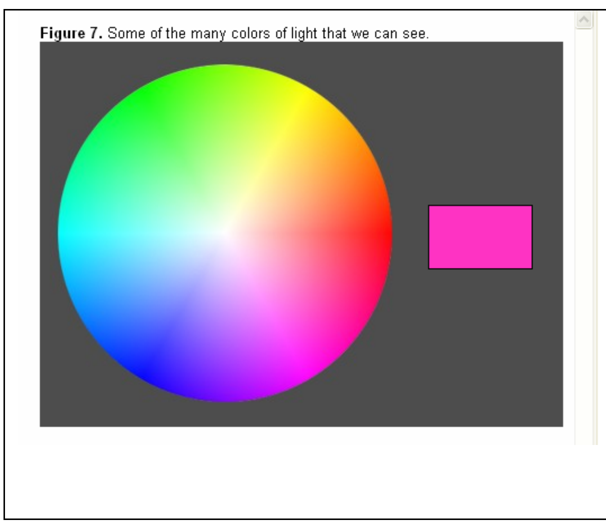
Figure 6b

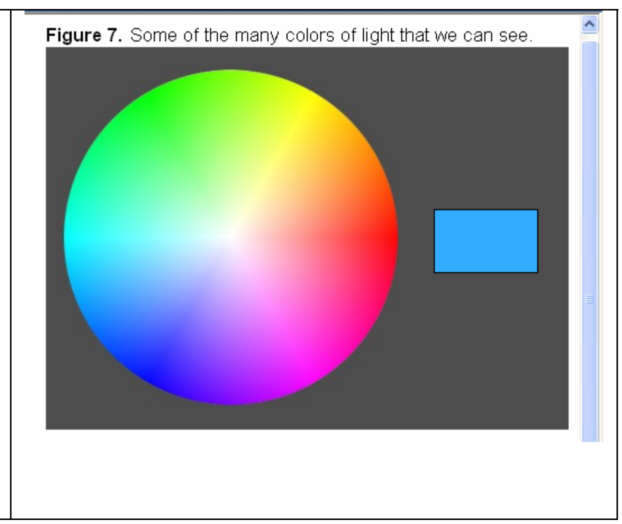
Important ideas: We see colors when specialized structures of the eye interact with light.

Affordances:

As readers in the Highlight & Animate Condition and readers in the Manipulable Graphics Condition move their cursor over the color wheel, the window beside the wheel shows the color upon which the cursor rests. Like page 5, page 8 is exactly the same in both the Highlight & Animate and Manipulable Graphics Conditions. There is no Highlight & Animate feature and minimal opportunity to manipulate the diagram.



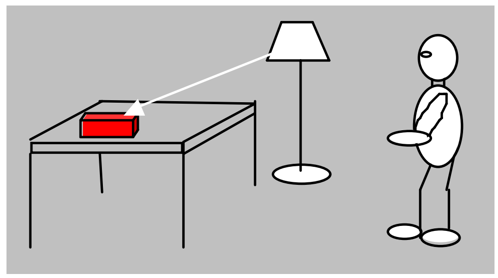




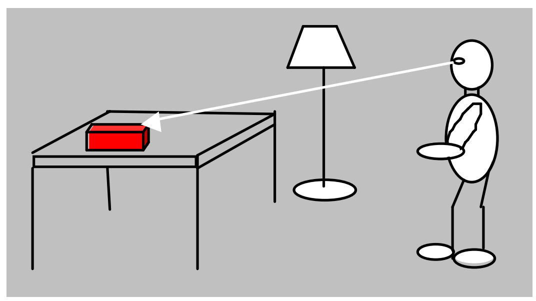
Appendix B: Pre-post Test of Knowledge about Light and Vision

1. **The white lines in each of these pictures show the path of light. Which picture shows how the person sees the book?**

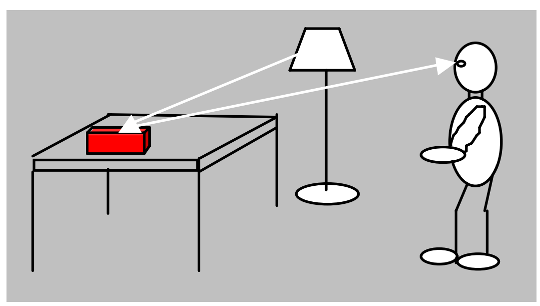
(a)



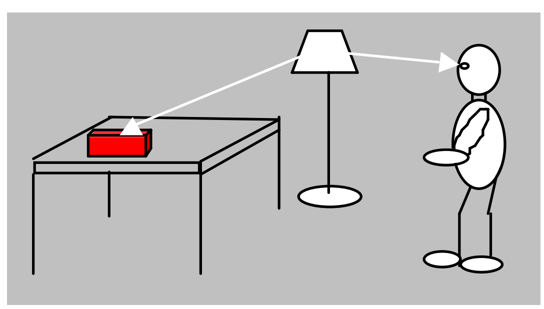
(b)



(c)



(d)



2. Amy says if you go deep enough into a cave where there are no lights, you won't even be able to see your hand in front of you.

Jenny says as long as our eyes are working, we can see.

With whom do you agree, and why?

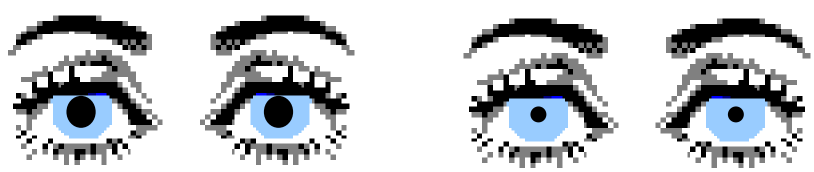
(a) Amy, because you need light to see.

(b) Amy, because the darkness of the cave blocks out the light.

(c) Jenny, because we can always see things that are near us.

(d) Jenny, because our eyes make light so we can see.

3. Time 1 Time 2



Look at the pupil, the dark spot in the middle of the eye.

Why did the size of the pupil change from Time 1 to Time 2?

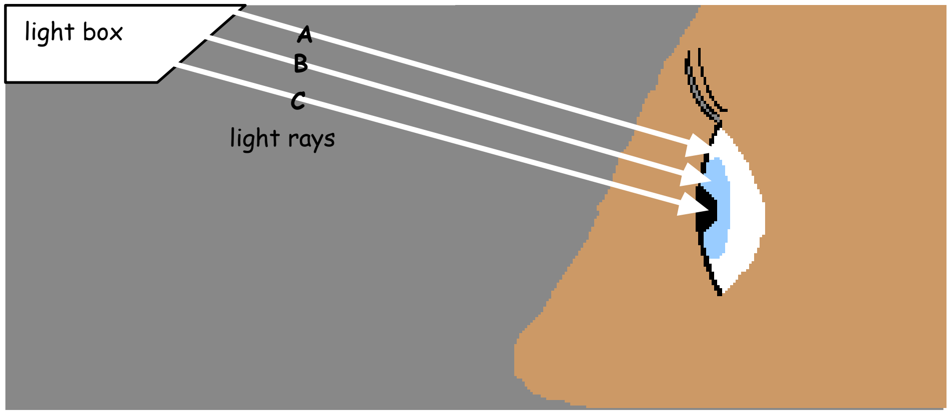
(a) The person walked into bright sunshine.

(b) The person walked into a closet.

(c) The person put on sunglasses.

(d) The person covered one eye with a hand.

4. Which light ray(s) will the person be able to see?



(a) A

(b) B

(c) C

(d) all of the light rays

(e) none of the light rays

5. What happens when a light ray strikes the retina?

(a) It reflects off the retina

(b) It sends a signal to the eyeball

(c) It reflects off the optic nerve

(d) It sends a signal to the optic nerve

6. Why does a stop sign look red?

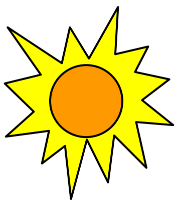
(a) It absorbs the red light that hits it.

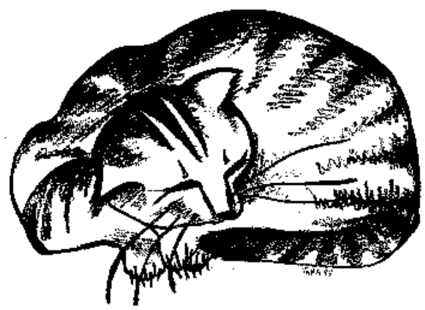
(b) It reflects red light to our eyes.

(c) It makes the light turn red.

(d) It is colored with red paint.

This striped cat is sleeping in the sun.





7. What happens when sunlight falls on the cat's stripes?

(a) Light is absorbed by the black and white stripes.

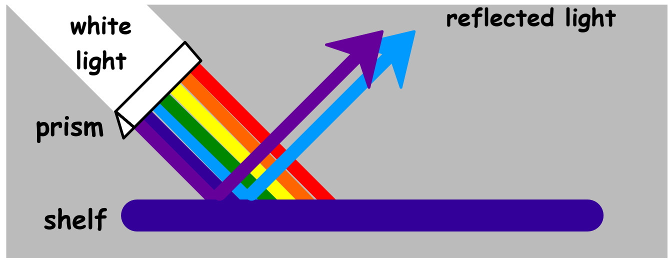
(b) Light is absorbed by the white stripes
and reflected by the black stripes.

(c) Light is absorbed by the black stripes
and reflected by the white stripes.

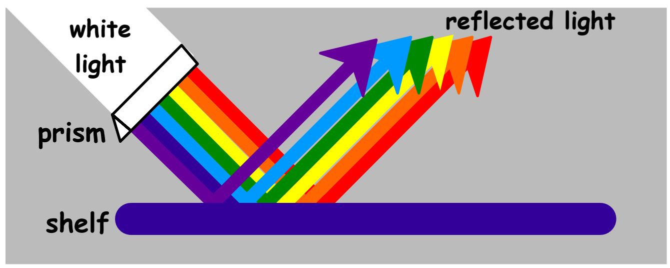
(d) White from the light is absorbed by the white stripes
and black from the light is absorbed by the black stripes.

8. **Which picture shows why the shelf looks dark blue?**

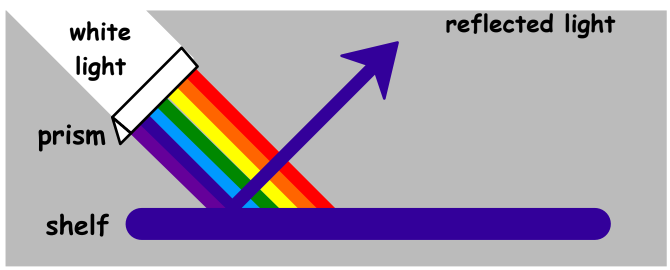
(a)



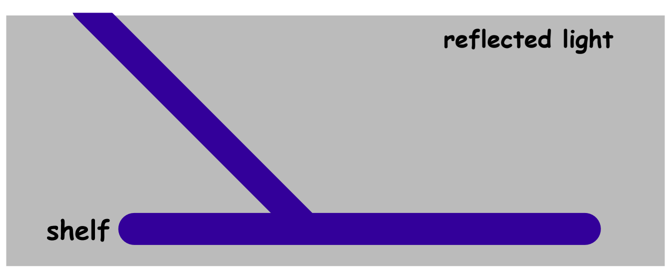
(b)



(c)

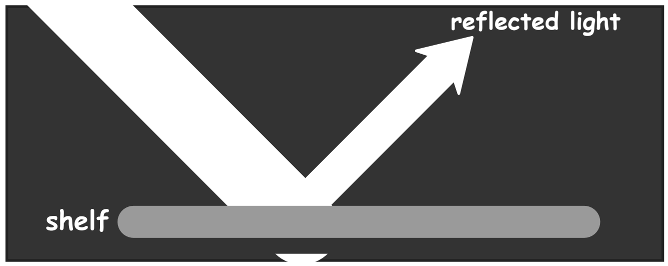


(d)

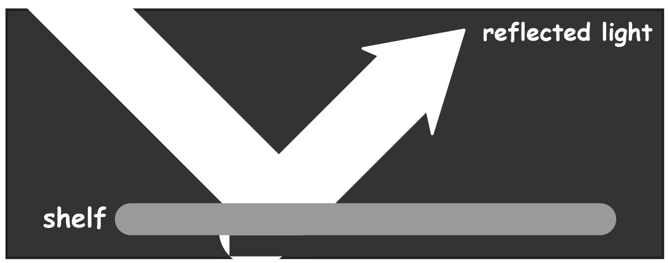


9. Which picture correctly shows what happens to the light?

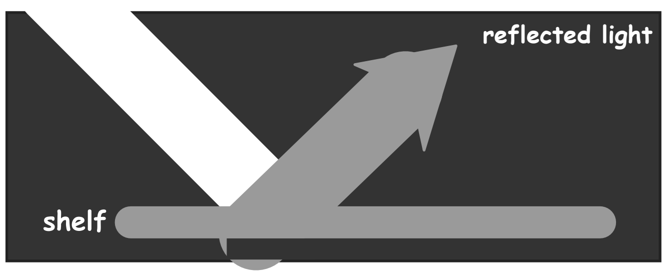
(a)



(b)



(c)



(d)

Appendix C: Pre-post Vocabulary Test

1. It will absorb. a. soak up b. prevent c. let go d. heat up	2. The road narrows. a. gets longer b. gets shorter c. gets thinner d. gets thicker
3. Examine the iris. a. colored part of the eye b. center part of the eye c. white part of the eye d. round part of the eye	4. It will reflect. a. go into b. curve around c. bounce off d. heat up
5. sensitive ears a. feel badly b. react easily c. look injured d. feel soft	6. a lot of evidence a. proof b. money c. notes d. ideas
7. He wanted to investigate. a. inform b. experiment c. arrest d. discover	8. She looked at the prism. a. triangular glass b. magnifying glass c. shiny jewel d. glass object
9. He sent a signal. a. light b. sound c. information d. picture	10. He will strike it. a. fix b. hit c. break d. miss

Appendix D: Sample Tutorial Protocol

INTERVIEWER'S SCRIPT FOR THE HIGHLIGHT & ANIMATE CONDIITION

DAY 1 TUTORIAL

Introduction:
We're very interested in learning how students read and learn on the computer. We've created a digital book called How Do We See This book has some special tools you can use to help you understand the ideas that you are reading about. We will start reading How Do We See next time.

Today, we're going to start with a practice activity about optical illusions. An optical illusion is something that fools your eye. The computer program will give you the chance to explore an optical illusion. At the same time, this activity will help you learn how to use the special computer tools.

Each page has some text and a diagram. You will read the text and see how the text and the diagrams work together.

Show Highlight & Animate Feature (called "animator" by children):
Here is a tool that will be helpful to your learning. Sometimes in a text there is an opportunity to make a connection between the ideas in the words and the ideas in the diagram. When this happens, the text might say something like "in the figure" *(point to this phrase in the first line on page one of the tutorial*) or "See figure 1."

We have also created a special tool to help you connect the ideas in the words and the diagrams. This tool is called the animator and it looks like this.
(Point to animator symbol.)

When you click on it, it will highlight some important words and it will change something in the diagram. The words say what the diagram shows, and the diagram helps you understand what the words mean.
(Child clicks on animator symbol.)

When you want to make the diagram go back to the way it was, press reset.
(Child clicks on reset symbol.)

Page 1 of tutorial
Now, please read page 1 aloud or read along as the computer or I read it aloud. Click on the animator button *(point to this button)* when you come to it. It will help you connect the ideas in the words and the diagram. Then, I will ask you what you understand about the ideas in the words and the diagram.
(Child reads aloud and activates animator. If child does not stop to click on animator button, prompt him/her to do so.)

Interview:
After child reads the page, wait for any spontaneous remarks, then ask: "What are you noticing on this page? What did you learn from that? How did you figure that out? Was the animator helpful to you? How was it helpful?"

Note phrases from student's response, give these back, and ask:
"Is there anything else you would like to add?"

Show other tools:
There are a few other tools that will be helpful to your learning.

Synonym:
This tool gives you another word that means the same thing.
(Child clicks on synonym symbol.)
Mistake is another word that means almost the same thing as misjudge.

Glossary:
If a word is colored in blue and underlined, it is important. Clicking on it will bring up the glossary where you can read the word's definition, sometimes a picture of the object, and see it used in a sentence.
(Child clicks on "illusion.")

Now press Go Back to go back to the read and animate page.
(Child clicks on go back symbol.)

You can also go to the glossary by clicking on glossary.
(Child clicks on glossary.)

You can find a word like "retina" by clicking on its first letter "r" and scrolling down.
(Child clicks on R.)

Now press Go Back to go back to the read and animate page.
(Child clicks on go back symbol.)

Highlighter:

This tool highlights the part of the diagram that illustrates the word, along with its label.
(Child clicks on the highlighter.)

Now go ahead and just try out the tools.
(Child uses tools freely.)
Page 2 of tutorial:
Arrow:
Now that we have finished page 1, let's move on to page 2. These arrows let you go forward and backward through the book, one page at a time.
(Child clicks on arrows.)

Highlight and Animate:
Please read page 2 aloud.
(Child reads aloud.)

TTS:
Let me show you a few more tools that tell the computer to read the words.

Read Highlighted Text:
You can select a word by double-clicking on it, or you can select one or more words by highlighting them. Then, you can ask the computer to read them by clicking on the "read highlighted text" button.
(Child highlights words and clicks on "read highlighted text" symbol.)

Step Ahead Stop:
You can also select the first word in a sentence and ask the computer to read the whole sentence by clicking on this "step ahead stop" button.
(Child highlights first word in a sentence and clicks on "step ahead stop" symbol.)

Read Continuously:
Or you can select the first word in a sentence and ask the computer to read the whole page by clicking on this "read continuously" button.
(Child highlights 1st word in a sentence and clicks on "read continuously" symbol.)

Read continuously and stop:
When the computer is reading, you may want it to stop instead of continuing all the way. You can use the stop button for that.
(Child uses read continuously and stop symbols.)

Conclude by asking the child to describe each tool and what it is used for

DAY 2 How Do We See

Review Tools:
Before we begin, let's review. Tell me what each tool does.
Refer child to sheet of tools.
Return to the tutorial to review any tools the child has forgotten.

Introduction to Read and Animate:
Now that you know how to use these tools, let's see how they can be helpful to learning about *How We See*. There are 8 pages of information that we will read today. You will read the page and study the diagram, using these tools *(point to tool review sheet)* to help you learn about the information on the page. When you are finished with all the pages, I will ask you to tell me what you have learned and to tell me what was helpful to your learning.

Please read each page aloud and remember that you can also ask the computer or me to read aloud for you. Also remember that while you are reading, you should stop to click on the animator buttons to help you connect the ideas in the words and the diagram. Remember to use the animator buttons to help you connect the ideas in the words with the ideas in the diagrams.

Read each page:

You're ready for page ___. Please read aloud or have the computer or me read. Child reads page.

If child does not click on an animator while reading, interrupt child's reading by pointing to the animator button and say,
"Click on the animator button."

After child clicks on animator, let him consider, then ask:
"What does this tool help you understand about the ideas in the sentence and in the diagram?"

Note phrases from student's response, give these back, and ask:
"Is there anything you would like to change about what I said? Anything you would like to add?"

Administer the content and vocabulary post-tests.

Appendix E: Rubrics for evaluating participants' knowledge articulated

Important Idea	Standards for Evaluating Responses	Highlight & Animate Condition Example	Manipulable Graphics Condition Example
We need light to see; we cannot see without light	Complete: Reports claim/big idea; i.e., we need light to see (in dark) or can't see without light; specific example of cave not required, but may be included	You need light to see in the dark	If there's no sunlight you can't see; if you don't have your headlamp then you can't see if there's no sunlight
	Adequate/Partial: Offers description of details of phenomena as pictured in specific example of cave, cannot see (hand), need a headlamp, without generalizing to our experience of seeing	some caves have um light, sunlight and when, sometimes they turn off, they turn off the light and um, it's so dark that they can't even see they own hand in front of their eyes	Some caves are dark enough that people can't really see their hands
	Inadequate: Notes mechanics of figure; statement is incorrect; or reports peripheral, rather than important aspect	Even though the, the um person got a light on his head, on the head, um, that they still can't see their hands... in front of them… under their eyes... with a headlamp	It's too dark. Now you can barely see the person; This doesn't just stay one size. You can change it to where it could get bigger, so you could see more; it could be so bright that you could even see behind the other stuff that you couldn't see before when the light wasn't as bright.
Light reflected from an object enables us to see the object	Complete: Includes cause-effect relationship and explanation of phenomena, i.e., light is reflected (bounced) from an object, and so we see the object; needs to make a reference to light (vs. line, it).	the light is going over the book… so you can't really see the light but it shows you the object that you're looking at.	Light bounces off and hits the person's eye…like light reflects off a object and bounces so you can see it
	Adequate/Partial: Describes phenomena that sets up the big idea, e.g., light reflects or bounces off an object, light goes to the eye; does not say that this helps us see objects; needs to make a reference to light (vs. line, it).	The white light go up first, then this line turns green, and this eye turns white… It reflects… (Reads) The light reflects upon the cover of the book reaches the person eyes.	if the beam hit the book, it would like shine back, like if you had a mirror and you had the sun beaming down on the mirror and it would bounce that way

Important Idea	Standards for Evaluating Responses	Highlight & Animate Condition Example	Manipulable Graphics Condition Example
	Inadequate: Notes phenomena of interest but statement is incorrect, or reports peripheral, rather than important aspect	Reflected light is… the easiest light you can see because it bounces off something so you can see it… the light like a lamp… will reflect the light so that you can see it	In a certain place, the light would hit a certain… like, where it is at right now, there's only one light rays going up, and when it's in the center two of them are going up
When light reflected from an object is blocked, we cannot see the object	Complete: Includes cause-effect relationship and explanation of phenomena, i.e., when light (reflected from the penny) is blocked (by the book), we cannot see (the penny) ; needs to make a reference to light here or earlier on this page	the light is reflecting off the penny, but it's hitting the book, but I don't understand how you wouldn't see the penny when it's like right there in front of the book	The penny (clicks on light 1) it hit the book - the person won't see it… if the penny's behind something and a book in front of it that light doesn't reflect and hit the eyes…
	Adequate/Partial: Describes phenomena re: the big idea, e.g., light is blocked or stopped; needs reference to light here or earlier.		on the first one [1st light aimed at penny], when I [book] was in the center, it hit the book, then when I was to the left it still hit the book but when it went to the right, it went over the book and it didn't hit it.
	Inadequate: Notes phenomena of interest but statement is incorrect, or reports peripheral, rather than important aspect	you need light to see something. So the light beam is going on to the penny and the eye is looking down at the penny and now he can see the penny.	A penny or whatever's laying down, it could reflect cause these if the book's brand new, the paper's kind of thick and probably kind of slippery and it's shiny so will reflect.
Light is not reflected from materials that are black	Complete: Includes cause-effect relationship and explanation of phenomena, i.e., light is not reflected from panda/materials that are black; looking for some reference to effect on seeing	black light it absorbs your own reflected light because you can't see... black light is like, the light, the um, the color that you can see without it reflecting.	it only hit the ear [which is black] and it won't bou-, a person won't see it.

Important Idea	Standards for Evaluating Responses	Highlight & Animate Condition Example	Manipulable Graphics Condition Example
	Adequate/Partial: Describes phenomena that sets up the big idea, e.g., light is not reflected	Only the white reflects off the panda and not the black. I see now... if it has black and white stripes, like a panda on the cover of the book, only the white stripes will reflect off of it, but not the black.	That when the light bounces off something, if it's not black it goes to your eyes. But if it's black it absorbs the light.
	Inadequate: Notes phenomena of interest but statement is incorrect, or reports peripheral, rather than important aspect, or formulates question about phenomena of interest.	What do this mean? In the figure light rays that strike black parts on the panda do not reflect?	This one just stops. (no mention of light anywhere on this page)
Light enables us to see when it enters the eye at the pupil	Complete: Includes functional relationship of light and structures of the eye, i.e., light enters eye though pupil; labels pupil; makes reference to light; optional: light that strikes blue & white parts of eye reflects/does not go in	Light rays that go into the pupil, it like helps your eyes to see; it can't like reflect out of your eye	Light bounces off and hits the person's eye…like light reflects off a object and bounces so you can see it
	Adequate/Partial: Describes phenomena in part, without clearly stating the relationship between light and the pupil, e.g., identifies pupil but does not say light enters here, describes path of 'it'/line/arrow but does not ever call it light	This one (traces 2nd Highlight & Animate) went through the pupil and (hovers over retina) went inside the eye	Most all of them went through the eyeball except 2; it could either go right to the eye or it could bounce off.
	Inadequate: Notes phenomena of interest but is incorrect, or reports peripheral aspect, or simply labels things	Reflections can't always be by each other really… they all go in different directions and if they don't, it goes, it stays in one thing… bam, bam, bam, bam… it's just like crushed up into one area… but um, it's better off to just don't have it all crushed up into one thing.	A pupil can go into the eyeball.

Important Idea	Standards for Evaluating Responses	Highlight & Animate Condition Example	Manipulable Graphics Condition Example
Light interacts with structures of the eye – the retina and optic nerve	Complete: Includes functional relationship between light and the structures of the eye, i.e., light interacts with structures both (mention both) the retina (which changes light to signals – optional) and the optic nerve	It's the pupil where the light source goes in and hits the retina and the retina sends the signal of the light to the optic nerve that leads to the brain.	If it (sunlight) goes in the pupil, it would hit the nerve, hit the retina, and then it would go to our optic nerve…
	Adequate/Partial: Describes phenomena re: the big idea, but may speak of only one of the important structures of the eye or may not be explicit in labeling 'light'	I never knew that it (the light) will hit the back of your eye and go through, go around the optic nerve. It showed me what the light does inside your eye and outside.	'That one' (traces light from source 3) goes straight but then it goes to the optic nerves
	Notes phenomena of interest but statement is incorrect, or reports peripheral, rather than important aspect	Okay, the retina's right here (points). Oh the optic nerve is right there (points). I wonder what's that yellow stuff coming in – I think it's the optic nerve.	So then they all kind of go through it (points where light 1 enters pupil)and they'll go down here 'cause it reflects this (points where light 1 hits retina)
The brain interprets signals from the light to tell us what we see	Complete: Includes functional relationship of light and eye, i.e., light signals are sent from the optic nerve to the brain which tells us what we see; looking for reference to seeing, brain, light (light reference may be nearby)	Your brain tells you what you are seeing. Did you know our eyes are connected to our brain?	I think these light source, these bounce and sends a message to the brain what is it or what does it mean.
	Adequate/Partial: Describes phenomena incompletely, e.g., fails to identify 'it' as light anywhere on the page, or make reference to brain, or to seeing as a result of signal traveling to brain	It would go to our optic nerve, to our head, brain	It like sends a signal (tracing signal from light source 3 – but no mention of 'light; anywhere on page) like it said to the um, to the um, brain
	Inadequate: Notes phenomena of interest but statement is incorrect, or reports peripheral aspect, e.g., simply labels	These little balls went up into… (tracing path)	That ah (traces optic nerve), thing to the brain or something.

Important Idea	Standards for Evaluating Responses	Highlight & Animate Condition Example	Manipulable Graphics Condition Example
The iris regulates the amount of light that enters the eye through the pupil	Complete: Includes cause-effect relationship, functional explanation of phenomena, i.e., the iris changes size (in response to light); in order to control the size of the pupil, or regulate amount of light entering the eye, or enable us to see	I learned that the iris controls the whole… the pupil and how big and how small it goes and how much light comes in.	None
	Adequate/Partial: Offers description of phenomena central to the big idea, i.e., the iris changes size; may note the correlation (w/o stating causal connection) between change in size of iris and change in size of pupil or change in amount of light, may notice that iris, not pupil changes size	Iris, it gets bigger, when the pupil gets smaller.	Actually the color parts changes not the, not the black part
	Inadequate: Notes phenomena of interest but statement is incorrect or too incomplete to interpret meaning, or indicates important idea is not understood, may ask question, or reports peripheral, rather than important aspect, e.g., color, use of contact lenses, mechanics of graphic	I got an iris. The iris don't move.	We actually do need this, the iris, around it; I don't know why .
The pupil admits more light in dim conditions, less light in bright conditions	Complete: Includes cause-effect relationships and functional explanation of phenomena, i.e., the pupil becomes larger in dim conditions to admit more light or so more light will reflect in, so we can see more; it becomes smaller in bright conditions when less light is needed to see or to protect eye from too much light.	When it's darker your pupil opens up wider so you, it helps you see more. But when the light is on your pupil gets smaller because you don't want it, too much light to get into your eyeball or it'll damage it.	When the light goes bright the pupil gets smaller cause… it wants like not that much light. And when it's dark some get, gather as much light as it can't see, can see in the dark.

Important Idea	Standards for Evaluating Responses	Highlight & Animate Condition Example	Manipulable Graphics Condition Example
	Adequate/Partial: Describes phenomena central to the big ideas, i.e., the pupil changes size in response to changes in amount of light; does not explain that the function of this action is to change the amount of light entering the eye, enable us to see better, or protect the eye from too much light.	In dim light it makes your eyes larger but if it's bright light it makes the pupil real little	When it's dark out the pupil gets bigger… And when it gets lighter out, the pupil gets smaller
	Inadequate: Notes phenomena of interest but statement is incorrect or too incomplete to interpret meaning (e.g., notes pupil changes size w/o noting correlation to changes in amount of light, or indicates important idea is not understood, may ask question, or reports peripheral, rather than important aspect	Your pupil get big and small	None
Light is absorbed or reflected by materials in proportion to its depth of color	Complete: Includes relationship of light and materials with which it interacts, refers to amount of light or depth of color, i.e., light is absorbed or reflected by materials depending on the color of the materials; materials reflect light to the eye in different amounts; lighter colors reflect more, darker colors reflect less	I'm thinking that when the light strikes the white or any other color than black it's going to shoot up, because on brown it shooted back up, but to the book, because the penny was lower…	Ah, it's not as dark (mixes gray). That's a pretty one. Now this one's bigger. The more light, it goes. . . Well, mostly I learned that ah... if you have the table black, then white doesn't reflect on it. If you have a table white, it reflects really good on your eyes and if you have it gray or light gray it reflects a little bit, or it reflects I guess a tiny bit.
	Adequate/Partial: Describes phenomena of interest, using a specific fact/example rather than bigger claim, e.g., black absorbs, white reflects, no reference to amount, degree, may be accurate, complete quote (light hitting black	I noticed that black objects absorb and white reflect. It was like a, it was a review on another one that we had done.	the white and the two kinds of grays both reflect the light and then the black just stays on the board… only black sticks there. And everything else bounces…no matter what kind of gray it's still going to bounce off of it. This is really dark (gray),

Important Idea	Standards for Evaluating Responses	Highlight & Animate Condition Example	Manipulable Graphics Condition Example
	and white materials)		but it still reflects and that’s a color.
	Inadequate: Notes phenomena of interest but does not address the main idea, e.g., describes activity of investigation without conclusions, or reports peripheral aspect only, or simply labels things, or is incorrect, or quotes partially, doesn’t contrast black and white.	That (reading) an important discovery they made was the black materials don’t reflects light because they absorb all the light striking them… That the light is observing into the eye part… That (reading) all the light strikes reflect.	if you put all the black in the cup and then the block gets black and then when you put the sensor on, it stops at the block, and when you put it on the white that it goes all the way up to the corner. And when you do it gray, it goes like in the middle. If you put more white and it gets lighter gray and black. And if you put more black than white then it gets darker gray.
Light is composed of colors	Complete: Includes relationship of light and color, e.g., light is made of colors, light contains colors; indicates that light was present even before it was directed through a prism and the prism revealed it; must talk about light; if these ideas are paraphrased from the prose they are ‘complete,’ if they are reread, virtually verbatim, they are ‘incomplete.’	White light is actually colored light; when we put the prism up, it shows colors	...if you have a prism and it shows every light. But the light on the table is the only light that you will see.
	Adequate/Partial: Offers description of phenomena central to the big ideas, without describing relationship, e.g., when light shines through prism we see colors (does not indicate that colors were present, if not visible to the eye, before the prism came);	it shows you the light source going to the prism and how it makes the color and then it’s absorbed	...if you have a prism and it shows every light. But the light on the table is the only light that you will see.
	Inadequate: Notes phenomena of interest but statement is incorrect, or reports peripheral, rather than important aspect, may ask questions trying to work out troublesome parts,	So, if there’s no prism it will reflect off but if there’s a prism it will absorb the light, it won’t reflect the light. I don’t really get it… What about the prism? What happens when it absorbs and what reflects off the prism or	None.

Important Idea	Standards for Evaluating Responses	Highlight & Animate Condition Example	Manipulable Graphics Condition Example
	refers to action of prism, but not to light	not?	
We see the color of light reflected from object; other colors of light are absorbed	Complete: Includes relationship of light and color to explain phenomena; includes reference to both reflected and absorbed: we see color of light reflected from object, other colors of light are absorbed; must include reference to light in response on this page; reference to seeing is optional	When it's darker your pupil opens up wider so you, it helps you see more. But when the light is on your pupil gets smaller because you don't want it, too much light to get into your eyeball or it'll damage it.	None
	Adequate/Partial: Describes phenomena central to the big ideas, but incompletely, e.g., describes pattern of object reflecting its own color but does not note that other colors are absorbed.	I think that, being that, um, "light absorb all the other colors and white light." The green light, I think that the, the colors go down and it stays there, but the green shoots back up, that's why the green light's only the one that, not just all the colors doing it, just the green. So the colors from the prism go just, goes down and stays down. But the green light shoots back up because that light shoots down on the green... so that like forces it to go up	So, (activates indigo, then blue) if there's all kinds of light, there's only one. (reactivates light source) Like that reflects the blue light... color (activates purple, then light source) and it reflects off that color (traces purple arrow off white material)… if you have a prism and it shows every light… but the light on the table is the only light that you will see
	Inadequate: Notes phenomena of interest but statement is incorrect, or reports peripheral, rather than important aspect	they absorb separate colors….green light absorbs all the colors	so it's like I want it purple (activates purple, light source) and it will be reflected light and then if you choose red, (activates red, light source) it'd go from the red. (points to red arrow reflecting off red material) But… if I use purple it'd come down right here (points where purple hits block) and the purple line won't come from the yellow, (points where yellow hits block) it'd come from the purple and you'd have reflected light with the prism, (points

Important Idea	Standards for Evaluating Responses	Highlight & Animate Condition Example	Manipulable Graphics Condition Example
			to prism, then to rainbow) with all of these and it would make reflected light
We see colors when specialized structures of the eye interact with light	Adequate/Complete: Explains how we see colors in terms of structures of eye – cones or retina – that interact with light; must mention the structure and that it enables us to see colors	So, our retina helps us detect different colors ‘cause it has cones in it.	You got special cells called cones that you can see so many colors of the light.
	Adequate/Partial: Describes phenomena of interest – that we see colors by means of structures of eye and brain – by quoting directly and correctly from the text; may refer to role of brain without reference to specific structures of the eye	Our eyes and our brain detected the colors.	When the light reaches the cones and it changes the signals to our brains and interprets.
	Inadequate: Notes phenomena of interest but does not address the main idea, e.g., reports that we see many different colors, or specific colors, but does not identify the structures of the eye - or brain - that enable us to interpret colors; or is incorrect, or partial quote does not make sense	It’s telling me that these are the colors that we see.	There is a lot of colors in the world that you can see.

Appendix F: Characteristics of participants' responses to important ideas - Evidence of Meeting Conceptual Challenges

Page	Important Idea	Condition	% Total, Accurate Statements	% Accurate, Complete Statements	% Accurate, Partial Statements
1	**We need light to see; we cannot see without light**	**HA**	91	**36**	**55**
		MG	44	**11**	**33**
2	**Light reflected from an object enables us to see the object**	**HA**	64	**27**	**36**
		MG	67	**22**	**44**
	When light reflected from an object is blocked, we cannot see the object	**HA**	82	**82**	**0**
		MG	56	**22**	**33**
	Light is not reflected from materials that are black	**HA**	91	**27**	**64**
		MG	67	**11**	**56**
3	**Light enables us to see when it enters the eye at the pupil**	**HA**	91	**45**	**45**
		MG	89	**55**	**33**
	Light interacts with structures of the eye – the retina and optic nerve	**HA**	91	**45**	**45**
		MG	44	**11**	**33**
	The brain interprets signals from the light to tell us what we see	**HA**	36	**36**	**0**
		MG	56	**22**	**33**
4	**The iris regulates the amount of light that enters the eye through the pupil**	**HA**	55	**27**	**27**
		MG	67	**0**	**67**
	The pupil admits more light in dim conditions, less light in bright conditions	**HA**	64	**27**	**36**
		MG	100	**22**	**78**
6	**Light is absorbed or**	**HA**	82	**9**	**73**

Page	Important Idea	Condition	% Total, Accurate Statements	% Accurate, Complete Statements	% Accurate, Partial Statements
	reflected by materials in proportion to its depth of color	**MG**	89	**67**	**22**
7	**Light is composed of colors**	**HA**	45	**9**	**36**
		MG	56	**22**	**33**
	We see the color of light reflected from object; other colors of light are absorbed	**HA**	82	**36**	**45**
		MG	89	**0**	**89**
8	**We see colors when specialized structures of the eye interact with light**	**HA**	55	**18**	**36**
		MG	33	**11**	**22**
All	**Mean**	**HA**	71	**33**	**38**
		MG	66	**21**	**45**

References

Afflerbach, P. (2000). Verbal reports and protocol analysis. In M. L. Kamil, P. B. Mosenthal, P. D. Pearson, & R. Barr (Eds.) *Handbook of reading research, Vol. III.* Mahwah, NJ: L. Erlbaum Associates.

Anderson, R. C. (1984). Role of the reader's schema in comprehension, learning, and memory. In R. C. Anderson, J. Osborn, & R. J. Tierney (Eds.), *Learning to read in American schools.* Hillsdale, NJ: L. Erlbaum Associates.

Anderson-Inman, L. & Horney, M. A. (2007). Supported e-Text: Assistive technology through text transformations. *Reading Research Quarterly,* 42(1), 153-160.

Anderson-Inman, L. & Horney, M. A. (1998). Transforming text for at-risk readers. In D. Reinking, M. C. McKenna, L. D. Labbo, & R. D. Keiffer (Eds.), *Handbook of literacy and technology: Transformations in a post-typographical world*. Mahwah, NJ: L. Erlbaum Associates.

Anglin, G. J., Vaez, H., & Cunningham, K. L. (2004). Visual representations and learning: The role of static and animated graphics. In D. H. Jonassen (Ed.), *Handbook of Research on Educational Communications and Technology* (2nd ed., pp. 865-916). Mahwah, NJ: Lawrence Erlbaum Associates.

Balajthy, E. (2005). Text-to-speech software for helping struggling readers. *Reading Online*. Retrieved April 18, 2008 from http://www.readingonline.org/articles/balajthy2/

Beck, I. & McKeown, M. (1991). Conditions of vocabulary acquisition. In R. Barr, M. L. Kamil, P. B. Mosenthal, & P. D. Pearson, (Eds.) *Handbook of reading research, Vol. II*. Mahwah, NJ: L. Erlbaum Associates.

Beck, I., McKeown, M. G., & Kucan, L. (2002). *Bringing words to life*. New York: Guilford Press.

Best, R. M., Rowe, M., Ozuru, Y., & McNamara, D. S. (2005). Deep-level comprehension of science texts: The role of the reader and the text. *Topics in Language Disorders*, *25*(1), 65-79.

Biancarosa, G., Palincsar, A. S., Deschler, D. D., & Nair, M. (2007). Adolescent literacy: Myths and realities. In D. D. Deschler, A. S. Palincsar, G. Biancarosa, & M. Nair (Eds.), *Informed choices for struggling adolescent readers: A research-based guide to instructional programs and practices.* Newark, DE: International Reading Association.

Blachowicz, C. L., Beyersdorfer, J., & Fisher, P. (2006). Vocabulary development and technology. In M. C. McKenna, L. D. Labbo, R. D. Keiffer, & D. Reinking (Eds.), *International handbook of literacy and technology, Vol. II*. Mahwah, NJ: L. Erlbaum Associates.

Blachowicz, C. L. & Fisher, P. (2000). Vocabulary instruction. In M. L. Kamil, P. B. Mosenthal, P. D. Pearson, & R. Barr (Eds.) *Handbook of reading research, Vol. III.* Mahwah, NJ: L. Erlbaum Associates.

Bransford, J. D., Brown, A. L., & R. R. Cocking (Eds.). (2000). *How people learn: Brain, mind, experience, and school.* Washington, D. C.: National Academy Press.

Buly, M. R. & Valencia, S. W. (2002). Below the bar: Profiles of students who fail state assessments. *Educational Evaluation and Policy Analysis, 24*(3), 219-239.

Bus, A. G., de Jong, M. T., & Verhallen, M. (2006). CD-ROM talking books: A way to enhance early literacy? In M. C. McKenna, L. D. Labbo, R. D. Keiffer, & D. Reinking (Eds.), *International handbook of literacy and technology, Vol. II*. Mahwah, NJ: L. Erlbaum Associates.

Caccamise, D., Franzke, M., Eckhoff, A., Kintsch, E., & Kintsch, W. (2007). Guided practice in technology-based summary writing. In D. S. McNamara (Ed.), *Reading comprehension strategies: Theories, interventions, and technologies.* New York: L. Erlbaum Associates.

Carlisle, J. F., Fleming, J. E., & Gudbrandsen, B. (2000). Incidental word learning in science classes. *Contemporary Educational Psychology 25*(2), 184-211.

Carlisle, J. F. & Rice, M. S. (2002). *Improving reading comprehension: Research-based principles and practices.* Baltimore, MD: York Press.

Catts, H. W., Fey, M. E., Tomblin, J. B. & Zhang, X. (2002). A longitudinal investigation of reading outcomes in children with language impairments. *Journal of Speech, Language, and Hearing Research*, 45(6), 1142-57.

Catts, H. W. & Kamhi, A. G. (2005). *The connections between language and reading disabilities*. Mahwah, NJ: L. Erlbaum Associates.

Center for Applied Special Technologies (2008). *NIMAS at CAST*. Wakefield, MA: Author. Retrieved March 14, 2008 from http://nimas.cast.org/index.html.

Chambliss, M. J. & Murphy, P. K. (2002). Fourth and fifth graders representing the argument structure in written texts. *Discourse Processes,* 34(1), 91-115.

Chard, D. J. (1998). Word recognition: Research bases. In E. C. Simmons & E. J. Kameenui (Eds.), *What reading research tells us about children with diverse learning needs: Bases and basics.* Mahwah, NJ: L. Erlbaum Associates.

Chi, M. T., de Leeuw, N. Chiu, M. & LaVancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive Science: A Multidisciplinary Journal*, 18(3), 439-477.

Coiro, J. & Dobler, E. (2007). Exploring the online reading comprehension strategies used by sixth-grade skilled readers to search for and locate information on the Internet. *Reading Research Quarterly*, 42(2), 214-257.

Cottrell, J. E., & Winer, G. A. (1994). Development in the understanding of perception: The decline of extramission perception beliefs. *Developmental Psychology, 30*(2), 218-228.

Dalton, B., & Palincsar, A. S. (2004). *Investigating verbal protocols for what they reveal about upper elementary students' text processing across narrative and informational texts.* Paper presented at the National Reading Conference Annual Meeting, San Diego, CA.

Dalton, B., Proctor, C. P., Palincsar, A. S., Mo, E. DeFrance, N., Robinson, K., Khasnabis, D., Vue, G., & Magnusson, S. (2006, November). *Reading to Learn: Investigating the effects of three versions of a digital reading environment featuring interactive diagrams and pedagogical agents.* Paper presented at the annual meeting of the National Reading Conference, Los Angeles, CA.

Dalton, B. & Proctor, C. P., (2007). Reading as thinking: Integrating strategy instruction in a universally designed digital literacy environment. In D. S. McNamara (Ed.), *Reading comprehension strategies: Theories, interventions, and technologies.* New York: L. Erlbaum Associates.

DeFrance, N. (2004, December). *The use of verbal protocols to understand the relationship between reading strategies and language resources in developing readers of informational text.* Paper presented at the annual meeting of the National Reading Conference, Miami, FL.

Dickson, S. V., Collins, V. L, Simmons, D. C., & Kameenui, E. J. (1998). Metacognitive strategies: Instructional and curricular basics and implications. In E. C. Simmons & E. J. Kameenui (Eds.), *What reading research tells us about children with diverse learning needs: Bases and basics.* Mahwah, NJ: L. Erlbaum Associates.

diSessa, A. A. (2007). An interactional analysis of clinical interviewing. *Cognition and Instruction* 25(4), 523-565.

di Sessa, A. A. (2004). Metarepresentation: Native competence and targets for instruction. *Cognition and Instruction, 22*(3), 293-331.

diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and Instruction, 10*, 105-225.

Driver, R. (1989). Students' conceptions and the learning of science. *International Journal of Science Education, 11*(special issue), 481-490.

Eaton, J. F., Anderson, C. W., & Smith, E. L. (1984). Students' misconceptions interfere with science learning: Case-studies of fifth-grade students. *Elementary School Journal, 84*(4), 365-379.

Englert, C. S. & Thomas, C. C. (1987). Sensitivity to text structure in reading and writing: A comparison between learning disabled and non-learning disabled students. *Learning Disabilities Quarterly*, 10, 93-105.

Fang, Z. (2005).Scientific literacy: A systemic functional linguistics perspective. *Science Education 89*(2), 335-47.

Fang, Z. (2006). The language demands of science reading in middle school. *International Journal of Science Education,* 28(5), 491-520.

Fortus, D., Hug, B., Krajcik, J. S., Kuhn, L., McNeill, K. L., Reiser, B. River, A., Rougat, A., Schwarz, C., & Schwartz, Y. (2006, April). *Sequencing and supporting complex scientific inquiry practices in instructional materials for middle school students.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco, CA.

Galili, I. & Hazan, A. (2000). Learners knowledge in optics: Interpretation, structure, and analysis. *International Journal of Science Education, 22*(1), 57-88.

George, C. L., Schaff, J. I., & Jeffs, T. L. (2005). Physical access in today's schools: Empowerment through assistive technology. In D. Edyburn, K. Higgins, & R. Boone (Eds.) *Handbook of special education technology research and practice.* Whitefish Bay, WI: Knowledge by Design.

Goldman, S. R. (2003). Learning in complex domains: when and why do multiple representations help? *Learning and Instruction, 13*, 239-244.

Graesser, A. C. (2007). An introduction to strategic reading comprehension. In D. S. McNamara (Ed.), *Reading comprehension strategies: Theories, interventions, and technologies.* New York: L. Erlbaum Associates.

Halliday, M. A. K. (1993). On the language of physical science. In M. A. K. Halliday & J. R. Martin (Eds.), *Writing Science: Literacy and discursive power.* Pittsburgh, PA: University of Pittsburgh Press.

Hegarty, M. (2004). Mechanical reasoning by mental simulation. *Trends in Cognitive Sciences, 8*(6), 280-285.

Hegarty, M., Carpenter, P. A., & Just, A. (1991). Diagrams in the comprehension of scientific texts. In R. Barr, M. L. Kamil, P. B. Mosenthal, & P. D. Pearson, (Eds.) *Handbook of reading research, Vol. II*. Mahwah, NJ: L. Erlbaum Associates.

Hegarty, M., Quilici, J., Narayanan, N. H., Holmquist, S., & Moreno, R. (1999). Multimedia instruction: Lessons from evaluation of a theory-based design. *Journal of Educational Multimedia and Hypermedia, 8*(2), 119-150.

Heywood, D. (2005). Primary trainee teachers' learning and teaching about light: Some pedagogic implications for initial teacher training. *International Journal of Science Education, 27*(12), 1447-1475.

Higgins, K., Boone, R., & Lovitt, T. (1996). Hypertext support for remedial students and students with learning disabilities. *Journal of Learning Disabilities*, 29(4), 402–412.

Horney, M. A., & Anderson-Inman, L. (1994). Hypermedia for readers with hearing impairments: Promoting literacy with electronic text enhancements. Paper presented at the National Reading Conference (San Diego, CA, November 30-December 4, 1994).

Johnson-Glenberg, M. C. (2007). Web-based reading comprehension instruction: Three studies of 3D-Readers. In D. S. McNamara (Ed.), *Reading comprehension strategies: Theories, interventions, and technologies.* New York: L. Erlbaum Associates.

Kamhi, A. G. (1991). Causes and consequences of reading disabilities. In A. G. Kamhi & H. W. Catts (Eds.), *Reading disabilities: A developmental language perspective*. Boston: Allyn and Bacon.

Kamil, M. L. (2003). Adolescent literacy: Reading for the 21st century. *Alliance for Excellent Education*. Retrieved April 1, 2006 from: http://all4ed.org/publications/AdolescentsAndLiteracy.pdf

Kendeou, P. & van den Broek, P. (2005). The effects of readers' misconceptions on comprehension of scientific text. *Journal of Educational Psychology*, 97(2), 235-245.

Kerawalla, L., Pearce, D., Yuill, N., Luckin, R. & Harris, A. (2008). "I'm keeping those there, are you?" The role of a new user interface paradigm – Separate Control of Shared Space (SCOSS) – in the collaborative decision-making process. *Computers & Education* 50, 193-206.

Kintsch, W. (1998). *Comprehension: A paradigm for cognition*. Cambridge, UK: Cambridge University Press.

Kletzien, S. B. (1991). Strategy use by good and poor comprehenders reading expository text of different levels. *Reading Research Quarterly,* 26(1), 67-86.

Kozma, R. (2003). The material features of multiple representations and their cognitive and social affordances for science understanding. *Learning and Instruction, 13*, 205-226.

Kozma, R. B. (1991). Learning with media. *Review of Educational Research, 61*(2), 179-211.

Langley, D., Ronen, M., & Eylon, B.-S. (1997). Light propagation and visual patterns: Preinstruction learners conceptions. *Journal of Research in Science Teaching, 34*(4), 399-424.

Lemke, J. L. (2000). Multimedia literacy demands of the scientific curriculum. *Linguistics and Education, 10* (3), 247-271.

Lemke, J. L. (2002). Multimedia semiotics: Genres for science education and scientific literacy. In M. J. Schleppegrell & M. C. Colombi (Eds.), *Developing Advanced Literacy in First and Second Languages* (pp. 21-44). Mahwah, NJ: L. Erlbaum Associates.

Lemke (2004). The literacies of science. In Saul, E. W. (Ed.), *Crossing borders in literacy and science instruction: Perspectives on theory and practice* (pp. 33-47). Newark, DE: International Reading Association.

MacArthur, C.A., Ferretti, R. P., Okolo, C. M., & Cavalier, A. R. (2001). Technology applications for students with literacy problems: A critical review. *Elementary School Journal*, 101(3), 273–301.

MacGinitie, W. H. (1999). *Gates-MacGinitie Reading Tests.* Itasca, IL: Riverside.

Martin, J. R. (1993). Literacy in science: Learning to handle text as technology. In M. A. K. Halliday & J. R. Martin (Eds.), *Writing Science: Literacy and Discursive Power*. Pittsburgh, PA: University of Pittsburgh Press.

Mayer, R. E. (2001). *Multimedia Learning*. Cambridge, England: Cambridge University Press.

Mayer, R. E. (2002). Using Illustrations to Promote Constructivist Learning from Science Text. In J. Otero, J. A. Leon & A. C. Graesser (Eds.), *The Psychology of Science Text Comprehension* (pp. 333-356). Mahwah, NJ: Erlbaum.

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*(4), 256-265.

McGregor, K. K. (2004). Developmental dependencies between lexical semantics and reading. In C. A. Stone, E. R. Silliman, B. J. Ehren, & K. Apel (Eds.), *Handbook of language and literacy: Development and disorders.* New York, Guilford Press.

McGuinness, D. (2005). *Language development and learning to read: The scientific study of how language development affects reading skill.* Cambridge, MA; MIT Press.

McNamara, D. S., O'Reilly, T., Rowe, M. Boonthum, C., & Levinstein, I., 2007). iStart: A web-based tutor that teaches self-explanation and metacognitive reading strategies. In

D. S. McNamara (Ed.), *Reading comprehension strategies: Theories, interventions, and technologies.* New York: L. Erlbaum Associates.

Meyer, B. J. F. (1984). *Text dimensions and cognitive processing.* In H. Mandl, N. L. Stein, & T. Trabasso (Eds.). Learning and comprehension of text. Hillsdale, NJ: L. Erlbaum Associates.

Meyer, B. J. F. & Wijekumar, K., 2007). A web-based tutoring system for the structure strategy: Theoretical background, design, and findings. In D. S. McNamara (Ed.), *Reading comprehension strategies: Theories, interventions, and technologies.* New York: L. Erlbaum Associates.

Moore, P. J., & Scevak, J. J. (1997). Learning from texts and visual aids: a developmental perspective. *Journal of Research in Reading*, *20*, 205-223.

Morocco, C. C. (2001). Teaching for Understanding with Students with Learning Disabilities: New Directions for Research on Access to the General Education Curriculum. *Learning Disability Quarterly*, *24*(1), 5-13.

National Center for Educational Statistics. (2006). *The Nation's Report Card*. Washington DC: Office of Educational Research and Improvement, U.S. Department of Education. Retrieved 4-7-2006 from: http://nces.ed.gov/nationsreportcard/reading/results/achieve.asp

National Center for Supported Electronic Text (2007). *The NCSeT Typology: Descriptions and Illustrations of Eleven Types of Supportive eText Resources*. Retrieved April 18, 2008 from http://ncset.uoregon.edu/index.php?option=com_content&task=blogcategory&id=44&Itemid=89

National Research Council (1996). *National Science Education Standards*. Washington, DC: National Academy Press. Retrieved 4-7-2006 from: www.nap.edu/html/nses/

No Child Left Behind Act, H.R. Res. 1, 107 Cong. (2001).

Okolo, C. M. (2005). Interactive technologies and social studies instruction for students with mild disabilities. In D. Edyburn, K. Higgins, & R. Boone (Eds.) *Handbook of special education technology research and practice.* Whitefish Bay, WI: Knowledge by Design.

Osbourne, J. F., Black, P., Meadows, J., & Smith, M. (1993). Young children's (7-11) ideas about light and their development. *International Journal of Science Education*, *15*(1), 83-93.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist*, *38*(1), 1-4

Palincsar, A. S. (2005). The unique role of literacy in different subject matter areas. Unpublished manuscript.

Palincsar, A.S., Dalton, B., DeFrance, N., Hapgood, S., Khasnabis, D., Proctor, P., & Magnusson, S. J. (Dec. 2004). Investigating verbal protocols for what they reveal about upper elementary students' text processing across narrative and informational text. Presented at the annual meeting of the National Reading Conference. San Antonio, TX.

Palincsar, A. S., Magnusson, S. J., Collins, K. M., & Cutter, J. (2001). Making Science accessible to all: Results of a design experiment in inclusive classrooms. *Learning Disability Quarterly, 24,* 15-32.

Park, O. & Hopkins, R. D. (1993). Instructional conditions fro using dynamic visual displays: a review. *Instructional Science* 21, 427-449.

Paris, S. G. (1991). Assessment and remediation of metacognitive aspects of children's reading comprehension. *Topics in Language Disorders, 12*(1), 32-50.

Pearson, P. D., Heibert, A. & Kamil, M. L. (2007). Vocabulary assessment: What we know and what we need to learn. *Reading Research Quarterly*, 42(2), 282-296.

Perfetti, C. A. (1985). *Reading ability*. New York: Oxford University Press.

Quintana, C., Chang, H., & Krajcik, J. (2007). Technology-mediated visualization and interpretation of chemical phenomena by middle school students. Presented at the annual meeting of the American Educational Research Association.

Raskind, M. H. & Higgins, E. L. (1999). Speaking to read: The effects of speech recognition technology on the reading and spelling performance of children with learning disabilities. *Annals of Dyslexia*, 49, 251-281.

Rieber, L. P. (1989). The effects of computer animated elaboration strategies and practice on factual and application learning in an elementary science lesson. *Journal of Educational Computing Research, 5*(4), 431-444.

Rieber, L. P. (1990a). Animation in computer-based instruction. *Educational Technology Research and Development, 38*(1), 77-86.

Rieber, L. P. (1990b). Using computer animated graphics in science instruction with children. *Journal of Educational Psychology, 82*(1).

Rieber, L. P. (1991a). Animation, incidental learning, and continuing motivation. *Journal of Educational Psychology, 83*(3), 318-328.

Rieber, L. P. (1991b). Effects of visual grouping strategies of computer-animated presentations on selective attention in science. *Educational Technology Research and Development, 39*(4), 5-15.

Robertson, Gary J. (2003). A practical model for test development. In C. R. Reynolds & R. W. Kamphaus, Eds., *Handbook of Psychological & Educational Assessment of Children,* (pp. 24-57), New York: Guilford.

Rose, D. H. & Meyer, A. (2002). *Teaching every student in the digital age: Universal design for learning.* Alexandria, VA: Association for Supervision and Curriculum Development.

Scarborough, H. S. (2005). *Developmental relationships between language and reading: Reconciling a beautiful hypothesis with some ugly facts.* Mahwah, NJ: Lawrence Erlbaum Associates.

Schleppegrell, M. J. (2002). Challenges of the science register for ESL students: Errors and meaning making. In M. J. Schleppegrell & M. C. Columbi (Eds.), *Developing Advanced Literacy in First and Second Languages*. Mahwah, NJ: Lawrence Erlbaum Associates.

Schwab, J. J. (1964). Structure of the disciplines: Meanings and significances. In, G. W. Ford & L. Pugno (Eds.) *The structure of knowledge and the curriculum*. Chicago, IL: Rand McNally.

Selley, N. J. (1996a). Children's ideas on light and vision. *International Journal of Science Education, 18*(6), 713-723.

Selley, N. J. (1996b). Towards a phenomenography of light and vision. *International Journal of Science Education, 18*(7), 837-846.

Shapiro, B. L. (1994). *What Children Bring to Light: A constructivist perspective on children's learning in science*. New York, NY: Teachers College Press.

Snow, C. E., Griffin, P., & Burns, M. S. (Eds.). (2005). *Knowledge to support the teaching of reading: Preparing teachers for a changing world.* San Francisco, CA: Jossey-Bass.

Stanovich, K. E. (2000). *Progress in understanding reading: Scientific foundations and new frontiers*. New York: Guilford Press.

Strangman, N. & Dalton, B. (2005). Using technology to support struggling readers: A review of the research. In D. Edyburn, K. Higgins, & R. Boone (Eds.) *Handbook of special education technology research and practice.* Whitefish Bay, WI: Knowledge by Design.

van den Broek, P., Kendeou, P., Kremer, K., Lynch, J., Butler, J., White, M. J., & Lorch, E. P. (2005). Assessment of comprehension abilities in young children. In S. G. Paris & S. A. Stahl (Eds.), *Children's reading comprehension assessment*. Mahwah, N.J.: L. Erlbaum Associates.

van den Broek, P., Young, M., Tzeng, Y., & Linderholm, T. (1999). The Landscape model of reading: Inferences and the online construction of memory representation. In H. van Oostendorp & S. R. Goldman (Eds.), *The construction of mental representations during reading*, pp. 71-98. Mahwah, NJ: L. Erlbaum Associates.

van den Broek, P., Virtue, S., Everson, M. G., Tzeng, Y., & Sung, Y. (2002). Comprehension and memory of science texts: Inferential processes and the construction of a mental representation. In J. Otero, J. A. Leon, & A. C. Graesser (Eds.), *Psychology of science text comprehension*, pp. 131-154. Mahwah, NJ: L. Erlbaum Associates.

Van Dijk, T. A. & Kintsch, W. (1983). *Strategies of discourse comprehension*. New York: Academic.

Veel, R. (1997). Learning how to mean – scientifically speaking: Apprenticeship into scientific discourse in the secondary school. In F. Christie & J. R. Martin (Eds.), *Genre and institutions: Social processes in the workplace and school*. London: Cassell.

Wagner, R. K., Muse, A. E., & Tannenbaum, K. R. (2007), Promising avenues for better understanding implications of vocabulary development for reading comprehension. In R. K. Wagner, A. E. Muse, & K. R. Tannenbaum (Eds.), *Vocabulary acquisition: Implications for reading comprehension.* New York: Guilford Press.

Weidenmann, B. (1994). Codes of instructional pictures. In W. Schnotz & R. W. Kulhavey (Eds.), *Comprehension of graphics.* New York: Elsevier Science.

Weisberg, R. & Balajthy E. (1989). Transfer effect of instructing poor readers to read expository text structure. In S. McCormick and J. Zutell (Eds.), *Cognitive and social perspectives for literacy research and instruction: 38th yearbook of the NRC*. Chicago: National Reading Conference.

Westby, C. (2002). Beyond decoding: Critical and dynamic literacy for students with dyslexia, language disabilities (LLD), or attention deficit-hyperactivity disorder (ADHD). In K. G. Butler & E. R. Silliman (Eds.), *Speaking, Reading, and Writing in Children with Language Learning Disabilities: New Paradigms in Research and Practice* (pp. 73-107). Mahwah, NJ: Lawrence Erlbaum Associates.

Wijekumar, K. K. (2007). Implementing web-based intelligent tutoring systems in K-12 settings: A case study on approach and challenges. *Journal of Educational Technology Systems*, 25(2), 193-208.

Wijekumar, K., & Meyer, B. J. F. (2005). Design and pilot of a web-based intelligent tutoring system to improve reading comprehension in middle school students. Retrieved March 2008 from: http://itss.br.psu/ITSS/pages/researchdoc.htm

Winer, G. A., Cottrell, J. E., Karefilaki, K. D., & Chronister, M. (1996). Conditions affecting beliefs about visual perception among children and adults. *Journal of Experimental Child Psychology, 61*, 93-115.

Wise, B. W. & Olson, R. K. (1995). Computer-based phonological awareness and reading instruction. *Annals of Dyslexia*, vol.45, 99-122.

Woodcock, R. W., Mc Grew, K. S., & Mather, N. (2001). *Woodcock-Johnson III Tests of Achievement.* Itasca, IL: Riverside.

Yuill, N. (2007). Visiting Joke City: How can talking about jokes foster metalinguistic awareness in poor comprehenders. In D. S. McNamara (Ed.), *Reading comprehension strategies: Theories, interventions, and technologies* (325-345). New York: L. Erlbaum Associates.