Supporting Productive Sense-Making in Text-Based Explanatory Modeling

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THESIS

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SUMMARY

The current study examined text-based inquiry for purposes of constructing an explanatory model of a biological phenomenon. Ninth-grade students were randomly assigned to one of two conditions of support: graphic organizer present or absent. While reading multiple texts and constructing models, students engaged in think-aloud protocols that were analyzed to shed light on their processing. The hypothesis that performance on both model construction and a learning application task would be higher for students with the graphic organizer was confirmed. Confirming the second hypothesis, analyses of students’ processing indicated that students with the graphic organizer engaged in more elaborative processing of relevant information from the texts than those without the graphic organizer. In the absence of the graphic organizer, processing was dominated by paraphrasing/summarizing of non-model relevant information from the texts. Confirming the third hypothesis, the effects of the graphic organizer on model construction, with respect to the number of elements included, and learning were mediated by elaborative processing of relevant information. These findings indicate that the graphic organizer encouraged deeper forms of processing, implying that it is not the scaffold itself, but rather the productive forms of processing that it encourages that leads to better model construction and learning. This study advances our understanding of the mechanisms that underlie the effects of scaffolds, like the graphic organizer, on successful text-based explanatory modeling. The findings imply that the utility of this and other scaffolds can be evaluated based on the extent to which they support students in identifying and deeply processing model relevant information.
INTRODUCTION

Scientists frequently engage in the construction of explanatory models—representations that seek to provide causal accounts of scientific phenomena—to help them generate explanations and predictions and communicate their ideas to other scientists (Schwarz et al., 2009; Schwarz & White, 2005). Many suggest that constructing explanatory models of scientific phenomena is one of the main goals of the discipline of science (e.g., Duschl, 2000; Lehrer & Schauble, 2006). Scientists frequently construct explanatory models based on data they collect through experiments or observations (Giere, 1988; Hestenes, 1992). They create these models to help them make sense of and explain these data and evaluate the extent to which their model accounts for the phenomenon that they are investigating (Giere, 1988; Hestenes, 1992). However, scientists also learn about scientific phenomena by reading research articles about the related work that other scientists have done (Yager, 2004; Osborne, 2002). As they read, they engage in inquiry with these texts—gathering, analyzing, and synthesizing different sources of evidence for the phenomenon that they are investigating (Bazerman, 1985). As part of this inquiry process, scientists often create explanatory models to help them understand and explain the phenomenon that they study. In fact, even scientists who are planning to conduct experiments to collect their own data take part in this reading process—engaging in inquiry with texts based on related work that other scientists have done and using this information to inform the experiments they plan to carry out (Latour & Woolgar, 1986). Importantly, the texts that scientists read and write commonly include both verbal text and visual representations, such as graphs, diagrams, and data tables (Kress, 2003; Lemke, 2004; The New London Group, 1996). In some areas of science, such texts are a primary source of information about phenomena of interest (e.g., plate tectonics).
The Next Generation Science Standards (NGSS) highlight the importance of engaging students in the authentic practices of science (Achieve, 2013). These standards reflect ongoing work by science educators and researchers that demonstrates the importance and value of engaging students in authentic disciplinary practices in the classroom, particularly through inquiry-based instruction (e.g., Edelson, 1998; Papert, 1960; White & Frederickson, 1998). A major focus of this work has been on engaging students in the construction of explanatory models of scientific phenomena (e.g., Lehrer & Schauble, 2006; Schwarz & White, 2005). Research suggests that explanatory modeling is valuable as a learning tool in that engaging students in the construction of models enables them to make visible and reflect on their thinking, which can help them advance towards more sophisticated understandings (Schwarz & White, 2005; Lehrer & Schauble, 2006). The modeling work has primarily focused on experiment-based modeling, in which students engage in investigations to collect their own data and construct models that account for and explain the data that they have collected (e.g., Krajcik, McNeil, & Reiser, 2008; Schwarz et al., 2012). However, relatively little work has been done to examine explanatory modeling when the relevant information is derived from texts (Goldman et al., 2016). Yet scientists frequently learn about phenomena by reading the work of other scientists and, in some fields of science, texts are a primary source of information. Therefore, it is important to uncover the processes involved in text-based explanatory modeling and identify sources of challenge for students. Such work is important to being able to effectively support students in text-based explanatory modeling.

There have been some investigations of text-based inquiry in science. For example, in the context of Project READI (http://www.projectreadi.org), students engaged in text-based inquiry with authentic science texts, such as research articles and medical reports (Greenleaf, Brown,
Goldman, & Ko, 2014). These texts include complex verbal text as well as visual representations, such as graphs and diagrams. Students use these texts for purposes of constructing explanatory models of scientific phenomena. The text sets that students engage with in this context are designed to require the selective use of information from multiple texts as well as synthesis within and across texts to produce a complete explanatory model (e.g., Greenleaf, et al., 2014). Although text-based inquiry for purposes of constructing explanatory models of scientific phenomena is an important part of authentic scientific practice, we have very limited understanding of students’ processing during this task.

Research on multiple text processing sheds light on some of the challenges that students might face during text-based explanatory modeling. To be successful, students must select relevant information from the texts, analyze the selected information, and identify connections, both within and across texts, to understand how the information fits together (e.g., Perfetti, Rouet, & Britt, 1999). Research suggests that students struggle to carry out these processes without support and that particular types of processing, such as the selection and elaborative processing of information from the most important and useful sources, may be related to more successful comprehension (e.g., Goldman et al., 2012; Wolfe & Goldman, 2005). However, apart from Goldman et al. (2012) much of the work on multiple text processing examined texts that are verbal and not about science phenomena. There may be additional opportunities and challenges introduced by engaging with both verbal text and visual representations of the types that occur in science texts (e.g., Goldman et al., 2012; Mayer, 2001; See Hegarty & Just, 1993 for work on processing of text and diagrams.)

The literature suggests that text-based inquiry for purposes of constructing explanatory models is an important, authentic scientific practice (e.g., Chinn & Malhotra, 2002; Lehrer &
Schauble, 2006) and indicates that this is a challenging task for students to carry out without support (e.g., Goldman et al., 2012). There is preliminary evidence that this process can be scaffolded effectively, but this proposal has not been rigorously examined (e.g., Ko et al., 2015; Matuk et al., 2012). A main purpose of the current study was to examine the effect of a graphic organizer scaffold on text-based explanatory modeling. To inform this investigation, a preliminary study was conducted to examine the feasibility of engaging adolescents in this challenging task. This preliminary study examined explanatory models that middle school students constructed using a text set that included both verbal text and visual representations (James, Ko, Goldman, Greenleaf, & Brown, 2014). Importantly, to build a complete explanatory model, students had to make use of information that was found in different texts in the set they were provided. Findings indicated substantial variation in the ways that students used information from the texts that were provided—particularly with respect to how many texts and what types of representations (verbal, visual representations) they used information from. It was also the case that students who used information from multiple texts created significantly higher quality models than those who used a single text, not surprising given the construction of the text set in relation to the information needed to construct an explanatory model. In other related work on Project READI, preliminary analyses of explanatory models constructed by 9th grade Biology students using text sets on several different topics, including homeostasis, revealed similar variation with respect to patterns of text use and quality of explanatory models. Of particular relevance to the present study, the Project READI students had a graphic organizer for recording evidence and interpretations from the texts. Informal observation of their use of the graphic organizer and the models they constructed indicated that a formal investigation of this type of scaffold would be worthwhile.
Thus, the main purpose of the current study was to examine the effect of a graphic organizer scaffold on text-based explanatory modeling. A second purpose was to address a limitation of these preliminary studies: lack of understanding of the processing that students engage in during text-based explanatory modeling. Indeed, the preliminary studies only examined the explanatory models that students constructed, not the students’ processing during the task. Based on prior research, we conjecture that there may have been important differences in how students used the texts, including the extent to which they attended to the parts of the text that contained information that was relevant to the model and the ways they analyzed information from the texts to construct understanding (e.g., Goldman et al., 2012). To better understand how students engage in text-based explanatory modeling, it is necessary to make their thinking visible during the task. Although there is preliminary evidence that particular scaffolds can effectively support students in text-based modeling contexts, we have very limited understanding of the mechanisms underlying their effects. The present study takes a step towards uncovering these mechanisms by making students’ processing visible through think alouds. The information about processing obtained through this methodology can be used to better understand the effects of the scaffold. This work will enable us to begin to understand the relationships between processing and successful modeling and learning in this context as well as how to support students to successfully carry out text-based explanatory modeling.
LITERATURE REVIEW

Explanatory Models in Science

A central goal of science, as a discipline, is to construct explanatory models of scientific phenomena (Duschl, 2000; Lehrer & Schauble, 2006). In science, explanatory models are representations that aim to provide causal accounts of phenomena and can be used to generate explanations and predictions (Schwarz et al., 2009; Schwarz & White, 2005). These representations commonly include multiple semiotic forms, including words as well as drawings (Krajcik, McNeill, & Reiser, 2008; Bazerman, 1985). When scientists gather data based on laboratory experiments or observations of scientific phenomena, they frequently construct explanatory models to help them understand and explain these data and evaluate the extent to which their model accounts for the phenomenon under investigation (Giere, 1988; Hestenes, 1992). However, scientists also learn about scientific phenomena by reading the work of other scientists (Osborne, 2002; Yager, 2004). In fact, scientists frequently work with text-based sources, such as research articles published by other scientists, to acquire information (Chinn & Malhotra, 2002; Osborne, 2002). Commonly, these research articles include verbal text as well as visual representation, such as graphs, tables, and diagrams (Lemke, 2004).

When scientists read articles to advance their understanding of a phenomenon, they engage in an inquiry process of collecting, evaluating, and synthesizing sources of evidence for the phenomenon that they seek to understand (Bazerman, 1985). This inquiry process engages scientists in constructing explanatory models to help them understand and explain the information they read about the phenomena they study (Bazerman, 1985). A classic example is the double helix model of DNA (Watson & Crick, 1953). In the years following the discovery of the DNA molecule (Miescher, 1869), a wealth of research articles containing scientists’ data,
theories, and models related to DNA were published, focusing on its chemical components and the ways these components might join together (Dahm, 2005). During this time, Rosalind Franklin conducted a series of X-Ray Crystallography experiments aimed at uncovering the structure of DNA. These experiments produced an image, called photo 51, which she published. Based largely on information from these research articles that included data from experiments carried out by other scientists, particularly Franklin’s photo 51, Watson and Crick (1953) created the double helix model of DNA, which accounted for and explained the existing data (Dahm, 2005).

Scientists also engage in inquiry with research articles when they are planning experiments to investigate particular phenomena (Brewer & Mishra, 1998; Latour & Woolgar, 1986). Scientists commonly begin by reading the related work that other scientists have done, examining their data, models, and theories, and often constructing explanatory models to make sense of the information (Latour & Woolgar, 1986). The experiments that they choose to do are informed by and often build upon the understanding that they construct during this inquiry process (Latour & Woolgar, 1986).

The text-based sources that scientists engage with for purposes of constructing explanatory models of scientific phenomena commonly include the forms of text—verbal text as well as visual representations, such as graphs and diagrams—that are part of the “new literacies” (Kress, 2003; Lemke, 2004; The New London Group, 1996). The concept of new literacies was put forth by The New London Group (1996) to reflect the fundamental reshaping of the forms and functions of text that have occurred in our increasingly technological society. Modern conceptions of text have broadened to accommodate not only traditional verbal text but also a multitude of other forms of representation, such as tables, diagrams, and graphs, that are now
commonplace due to the availability and usability of the technology needed to create them (Kress, 2003). Indeed, Lemke (2004) points out that reading in science now commonly involves engagement with texts that include both verbal text and visual representations. In his analysis of the semiotic forms commonly found in scientific research articles, Lemke (1998) found that a typical Biology article had six visual representations, including at least one table and one graph.

**Inquiry-Based Science Instruction**

Current science education standards emphasize the importance of engaging students in the authentic practices of science. (Achieve, 2013; National Research Council Framework, 2012). The National Research Council framework (2012) suggests that students cannot fully understand scientific concepts without also participating in the practices through which these ideas are developed. The science standards reflect longstanding calls by educators and researchers emphasizing the importance and value of engaging students in authentic disciplinary practices in the classroom (e.g., Brown, Collins, & Duguid 1989; Edelson, 1998). One of the ways that this is commonly done in the science classroom is through inquiry-based learning (e.g., Bruner, 1961; Papert, 1980). Research suggests that involving students productively in authentic forms of scientific inquiry supports understanding of scientific concepts (e.g., Lee, Linn, Varma, & Liu, 2010; White & Frederickson, 1998), understanding of the processes of scientific inquiry (e.g., Bell, Blair, Crawford, & Lederman, 2003), and interest in science learning (e.g., Welch, Klopfer, Aikenhead, & Robinson, 1981).

One of the scientific practices emphasized in the Next Generation Science Standards (NGSS) is inquiry for purposes of constructing models of scientific phenomena (Achieve, 2013). Inquiry-based modeling instruction engages students in forms of this authentic scientific practice. Proponents of inquiry-based modeling instruction point out that constructing explanatory models
helps students develop understanding of complex scientific phenomena because these representations make visible the key elements and causal relationships involved (Schwarz & White, 2005; Lehrer & Schauble, 2006). The construction of explanatory models also enables students to externalize and reflect on their own thinking, which, in turn, can help them advance towards higher-level understanding. Research suggests that involving students in constructing explanatory models through inquiry-based investigations leads to more sophisticated conceptual understanding of science content as well as epistemological understanding of the nature of science (Schwarz & White, 2005; Lehrer & Schauble, 2006).

Much of the work that has been done to examine students’ engagement in inquiry-based modeling has focused on experiment-based modeling in which students carry out experimental investigations and construct models that account for and explain their own experimental data (Schwarz et al., 2009; Krajcik et al., 2008). However, as previously discussed, models can also be constructed based on the data, theories, and models reported in text-based sources, such as research articles. (Bazerman, 1985; Latour & Woolgar, 1986). We know little about students’ engagement in this other form of inquiry that is central to the practices of scientists—text-based inquiry for purposes of constructing explanatory models (Goldman et al., 2016). Given that this is a common practice of scientists, it is important to understand how to support students to engage productively in inquiry with texts for purposes of constructing explanatory models. Indeed, the NGSS also highlight the importance of supporting students to engage in constructing understanding from scientific texts (Achieve, 2013). In fact, the standards emphasize that 9th-12th grade students should be able to “compare, integrate, and evaluate” sources of scientific information presented in different representational forms (e.g., visual, quantitative) as well as verbal text (Achieve, 2013).
Text-based Inquiry Instruction

Science educators and researchers have developed instruction that involves students in various forms of text-based inquiry. For example, in the context of Web-Based Inquiry Science Environments (WISE), students participate in scaffolded inquiry with visual texts, including data, graphs, and diagrams, as well as small amounts of verbal text, in a web-based environment (Linn et al., 2003). Students use these texts for a variety of purposes including constructing models, arguments, or explanations, among other activities (Linn & Slotta, 2000). This work focuses on supporting knowledge integration with respect to the text-based information that students encounter in this context as well as relevant prior knowledge (Linn et al., 2003).

Importantly, the texts in this environment include limited amounts of verbal text. This was intentional on the part of the designers who did not want traditionally defined reading comprehension problems to interfere with knowledge integration and sense-making. Nevertheless, even minimizing traditional sources of reading comprehension difficulty, Linn and colleagues have found that it is challenging for students to integrate across sources (Davis & Linn, 2000; Matuk et al., 2012). To better understand how to effectively support students in this difficult task, they conducted pilot research on the effects of scaffolds, such as metacognitive prompts and graphic organizers, and found preliminary evidence that these types of supports effectively facilitate productive forms of processing.

In the context of Project READI, students participate in another form of text-based inquiry that is rooted in—and dependent on—close reading with multiple texts (Goldman et al., 2009; Greenleaf et al., 2014). This task involves students in using a variety forms of representation, including words as well as drawings, to represent and communicate the
explanatory models that they construct based on the information in the texts (e.g., James et al., 2014).

The text sets that students use for purposes of constructing explanatory models in the READI context include verbal text as well as visual representations, such as tables, graphs, and diagrams (Goldman et al., 2009; Greenleaf et al., 2014). In this context, text sets are designed so that each text provides particular parts of the targeted explanatory model, but no single text provides the entire explanation. Students are provided an inquiry question related to a particular scientific phenomenon and asked to construct an explanatory model that provides a causal, evidence-based explanation of the phenomenon using information from the texts. For example, they might be provided with a text about excessive water intake and a text about sodium and water balance in the body and be asked to explain how drinking too much water impacts sodium and water balance in the body. To successfully complete this task, students must select relevant information from the texts, analyze the information they select, and reason about how the relevant information fits together, both within and across texts, to construct the explanatory model. Further, they must also make meaning conjointly with the different forms of representation present in the text set- including verbal text and visual representations (Lemke, 2004). Although this task is an important part of authentic scientific literacy, we have very limited understanding of the ways that students engage in this task and sources of challenge they face.

One of the main purposes of the present study is to examine the processing that students engage in during inquiry with multiple texts that include verbal text and visual representations for purposes of constructing explanatory models of scientific phenomena. Prior research on this topic is somewhat limited in that in much of the work the purpose is not to construct an
explanatory model, but rather to make a judgment about a socioscientific issue (e.g., Braten & Stromso, 2009). Nevertheless, research on text processing provides a starting point for unpacking the types of processing that students engage in and sources of difficulty they experience during text-based explanatory modeling.

**Learning from Multiple Texts**

Researchers have proposed several models of the processes involved in text processing. In the most widely adopted model, Kintsch (1998) described text comprehension as a process through which learners attempt to construct mental representations of the information in a text. At the deepest level of representation, individuals construct a situation model that encompasses the important concepts in the text as well as the causal relationships among these concepts and that is integrated with readers’ topic related prior knowledge. This is contrasted with a textbase representation that encompasses the ideas in the text and text-based inferences that connect the ideas in the text (Kintsch, 1998). Successful readers achieve deep comprehension by actively engaging with what is in the text—making connections between and inferences across concepts, often relying on prior knowledge, to construct a situation model representation (Coté, Goldman, & Saul, 1998; Goldman, Braasch, Wiley, Graesser, & Brodowinska, 2012). In contrast, less successful readers tend to “stick to the text,” restating information that is in the text and making inferential connections within the text but not to other texts or prior knowledge (Coté et al., 1998; Goldman et al., 2012).

Models of multiple text processing, such as the Documents Model framework, build on these single text models (Perfetti et al., 1999). They suggest that in addition to the construction of a situation model for each text, students must also develop a situations model that reflects the overall understanding of the phenomenon from synthesizing across a set of texts, and an intertext
model, which contains metainformation about individual texts and information about the 
relations between texts (Perfetti et al., 1999).

Research on multiple-text processing suggests that constructing understanding across 
multiple texts is challenging. For example, undergraduate students struggle with using 
information from and synthesizing within and across multiple texts (Goldman et al., 2012; Wiley 
et al., 2009). Students tended to approach each text separately and uncritically, failing to notice 
connections between them. In some cases, student work only showed evidence of using 
information from a single text. Even when student work showed evidence of using information 
from multiple texts there was little evidence of synthesis. In fact, students tended to simply list 
information from each text separately.

However, when deeper processing does occur it tends to be associated with deeper levels 
of comprehension (Wiley & Voss, 1999; Wolfe & Goldman, 2005). For example, using think-
aloud protocols in the context of historical inquiry, Wolfe and Goldman (2005) examined and 
categorized the processing strategies that adolescent students engaged in during text-based 
inquiry with multiple texts. One important distinction was between paraphrase and elaborative 
processing. Paraphrasing is a process that sticks very close to the text by reorganizing the words 
or providing synonyms or phrases that are equivalent to the stated information. In contrast, 
elaborative processing involves adding meaning to and making inferences about information in 
the text, often drawing on prior knowledge of the topic in efforts to explain to oneself what the 
text is saying (Wolfe & Goldman, 2005; Chi, 2000). Wolfe and Goldman (2005) found that 
elaborative processing significantly predicted more complex understanding of a historical event. 
Thus, elaborative processing may play an important role in the construction of understanding 
from multiple texts.
Researchers have also examined the information selection strategies that are used by successful learners when engaging with multiple texts. Using think aloud protocols, Goldman et al. (2012) examined the selection and processing of information from multiple internet sources by better and poorer learners in the context of a science inquiry task. The internet sources included both reliable and unreliable sources. They found that successful learners engaged in more self-explanation on reliable sources as compared to unreliable sources and that the difference between self-explanation on reliable and unreliable sources was greater for the better learners than the poorer learners. Thus, selection and elaborative processing of information from the most important and useful sources may be related to successful construction of understanding in text-based science inquiry.

Researchers have also examined the role of task-relevant reading goals in multiple-text processing. They suggest that readers use their understanding of a reading task to form a set of reading goals (Rouet & Britt, 2011). These reading goals vary depending on the objectives of the reading task (e.g., reading for entertainment, reading to construct an explanatory model) and include specific actions and procedures necessary to achieve the goal and criteria for determining when the reading goal has been achieved. Especially in multiple text processing, the reader’s goals guide the process of selecting which texts to use and what information to use from those texts and can therefore impact the extent to which readers synthesize information within and across texts (Rouet & Britt, 2011). Indeed, Bråten and Strømsø (2009) examined the impact of task instructions on undergraduate students’ understanding of multiple texts about climate change. They found that readers who were given the tasks of constructing arguments developed deeper, more integrated understandings from the texts than those given the task of producing a general overview. Similarly, Cerdán and Vidal-Abarca (2008) found that undergraduate students
who were asked to write an essay explaining how antibiotic resistance develops showed deeper learning and more synthesis than those who were asked to answer a series of specific questions about the phenomenon. These findings suggest that reading task can play an important role in multiple-text processing in science.

Text processing research provides insight into some of the challenges that students may face as they engage with multiple texts for purposes of constructing explanatory models of science phenomena. This work also reveals the information selection and processing strategies, including the selection of important, useful information and elaborative processing of that information, that lead to more successful comprehension of multiple texts (Wolfe & Goldman, 2005; Goldman et al., 2012). Other research has more explicitly focused on processes that come into play when texts contain representations beyond traditional verbal text.

**Engaging with Verbal Text and Visual Representations**

In text-based explanatory modeling in science, students use text sets that include verbal text as well as visual representations, such as graphs and diagrams (Goldman et al., 2016; Greenleaf et al., 2014). Engaging with both verbal text and visual representations introduces a layer of complexity beyond the processing of multiple verbal texts in that students encounter multiple modes and conventions for communicating information and must translate information from one representational mode to another (e.g., Ainsworth, 1999; Hegarty & Just, 1993; Lemke, 2004). During text-based explanatory modeling, students engage with several different forms of representation, including verbal text, graphs, and diagrams. The literature suggests that different modes of representation serve different functions and provide unique learning opportunities with respect to constructing understanding of complex scientific concepts (Ainsworth, 2008; Mayer, 2001). Indeed, Schnotz (2002) pointed out that there are fundamental differences between verbal
representations, such as verbal text, and visual representations, such as graphs and diagrams. He suggests that verbal text is a descriptive form of representation in that it uses a symbol system that relates to the represented information only through convention, whereas visual representations are depictive in that they use iconic signs that communicate structural properties of the represented information. As a result, verbal text and visual representations have important differences with respect to the information that they can convey (Schnotz & Bannert, 2003). For example, graphs can allow perceptual patterns, such as the effects of excessive water intake on the amount of sodium in the blood over time, in data to be seen whereas verbal texts can provide explicit descriptions, which can make clear the distinctions and relationships that exist among particular concepts and categories (Pittenger, 1995; Kress, 2003). Thus, the multiple modes of text that students engage with during text-based explanatory modeling differ in terms of their representational affordances with respect to communicating particular ideas and information.

Some researchers argue for the benefits of using multiple modes of representation to present information while others argue that it presents a unique set of challenges (see for review Van Someren, Reimann, Boshuizen, & de Jong, 1998). For example, Paoletti (2005) found that most undergraduate students who engaged with a text and a corresponding graph for purposes of constructing understanding did not synthesize across these forms of representation and many only made use of the text (see also Kozma, 2003; Kozma & Russell, 1997). Thus, engaging with verbal texts and visual representations introduces complexities beyond those involved in processing only verbal information.

**Curricular Scaffolds**

Researchers and educators, including science educators, have sought to develop scaffolds that support students in effectively constructing understanding across multiple sources. For
example, one type of scaffold has focused on supporting students to identify and map connections across sources, using various design features that emphasize the connections between representations by underscoring the corresponding elements in different sources of information (see for review Mayer, 2005). Importantly, research suggests that these scaffolds may provide too much support and may not promote active processing of the representations, prompting students to rely on surface-level connections rather than identifying deep conceptual connections (Bartholomé & Bromme, 2009; Seufert, 2003).

Another type of scaffold prompts students to explain their reasoning. There is substantial evidence that engaging students in various forms of self-explanation supports deep processing of information in that it supports students to actively engage with the materials and effectively monitor their emerging understanding (e.g., Chi, 2000). In fact, self-explanation promotes inference generation, synthesis of materials, and integration of prior knowledge (Chi, 2000). Roy and Chi (2005) suggest that prompting students to engage in self-explanation while they examine multiple representations might facilitate synthesis across representations. They suggest that explanation in this context might prompt students to focus on conceptual similarities and differences between representations, prompting meaningful integration. Indeed, Aleven and Koedinger (2002) found that prompting students to generate self-explanations while engaging with multiple representations helped them integrate verbal and visual information in mathematics.

Another type of scaffold, double entry charts, has been used to support students at becoming more metacognitive about what they are reading (Schoenbach et al., 2012). Double entry charts are designed to support students in close reading of complex texts by prompting them to identify and record important information from the texts. The utility of these charts can
be varied by the kinds of questions students are prompted to think about. Preliminary analyses of students’ use of double entry charts in the context of Project READI suggest that use of these scaffolds supports students’ productive engagement in close reading with multiple science texts (Ko et al., 2015)

Researchers have also developed tools that incorporate several types of scaffolds aimed at supporting students to use text-based information to construct explanations. For example, McElhaney et al. (2012) developed the Idea Manager, a computer-based tool designed to support students in constructing explanations that integrate information from multiple texts as well as relevant prior knowledge. This tool is comprised of two components: the Idea Manager and the Explanation Builder. The Idea Manager is a place for students to track their own related prior knowledge and record relevant information from the texts they read. In the Explanation Builder, students drag and drop the relevant information they have recorded into a sorting space where they arrange the information to begin to organize their ideas and build their explanation.

Research on the effects of this scaffold on comprehension is limited, but preliminary analyses of students’ use of this tool suggest that it effectively supports students in closely attending to the information they encounter in the texts (Matuk et al., 2012). The current study builds on and draws from double entry charts and the Idea Manager to inform the design of a graphic organizer that was intended to support students in effectively carrying out multiple aspects of text-based explanatory modeling, particularly selecting relevant information, elaboratively processing the selected information, and noticing connections across texts.

Text-Based Explanatory Modeling in Science: Preliminary Investigation

The research literature reviewed above suggests that text-based inquiry for purposes of constructing explanatory models is an important, authentic scientific practice (e.g., Chinn &
Malhotra, 2002; Lehrer & Schauble, 2006) that is challenging for college students whether it is in history, science, or socioscientific domains (e.g., Goldman et al., 2012). As well, it suggests that the process can be scaffolded effectively, but this proposal has not been rigorously examined for adolescent science learners (e.g., Ko et al., 2015; Matuk et al., 2012). A primary purpose of the current study was to test the effect of a scaffold on text-based explanatory modeling. Toward that end, a preliminary study was conducted to explore the feasibility of engaging adolescent students in inquiry with multiple texts for purposes of constructing an explanatory model of a biological phenomenon (James et al., 2014). In that study, 22 6th grade students created explanatory models describing how human carbon use affects the Earth’s temperature. They used information from a set of four texts that provided information about the carbon cycle. The text set included verbal text, a graph, and two causal diagrams and was designed to require the selection and elaborative processing of relevant information from the texts and reasoning about how that information connects, both within and across texts, to construct the explanatory model.

Using a series of rubrics, we analyzed the explanatory models that students constructed to determine the extent to which they made use of the texts and the quality of the models that they created. Underlying this analysis was the notion that explanatory models are comprised of elements that reflect the important components involved in the explanation of the phenomenon and links that connect these elements together to form the explanation. We found substantial variation in the extent to which students made use of the texts that were provided during this task. Consistent with prior research, we found that many students only used information from a single text to construct their models (e.g., Goldman et al., 2012). Some students included information from multiple texts in their models and a few students did not make use of information from any of the texts. Those students who included information from a single text
tended to use one of the two visual texts in the text set. In contrast, most of the multiple text users included information from both verbal texts and visual texts. This suggests that single text users largely relied on visual representations to create their models whereas multiple text users engaged with both verbal texts and visual representations. We also found that variation in text use was related to important differences in the quality of the explanatory models that students constructed, a finding consistent with prior work on multiple text processing in history (Wolfe & Goldman, 2005). Multiple text users produced significantly higher quality models than single text users with respect to the number of elements that they included in their models.

The data from this preliminary study provided evidence of interesting variations in students’ use of multiple texts to construct explanatory models and suggested that these differences in text use were related to important differences in the quality of the models that were constructed. At the same time, preliminary analyses of explanatory models constructed by 9th grade Biology students participating in Project READI revealed similar variation among students in model quality and patterns of text use inferred from informal observations of students’ processing. As well, the READI students were provided with graphic organizers for recording evidence and interpretations from texts. Informal observations of students’ use of this scaffold and the models they constructed suggested their utility for text-based explanatory modeling and the value of a more formal test of the effects of this type of support. Hence, the main purpose of the current study was to examine the effects of a graphic organizer scaffold on text-based explanatory modeling.

A second main purpose of the current study was to address a major limitation of these preliminary studies and analyses: lack of information about the processing that students engage in during text-based explanatory modeling. Because we had no information about how students
were processing the information as they read the texts and constructed their models, we inferred which and how many texts students had drawn on to construct their models, based on the contents of the completed models. Based on findings from prior studies on the relationship between types of processing and the quality of the product of that processing, we suspected that examining students’ processing would reveal differences in how they engaged with the texts along a number of dimensions, including the extent to which they attended to model-relevant information, how they analyzed information, and whether they made connections within and across texts (e.g., Goldman et al., 2012; Wolfe & Goldman, 2005). To explicitly elicit students’ processing, two methods have been used in past research: concurrent think alouds (e.g., Wolfe & Goldman, 2005) and retrospective interviews (Schoenfeld, 1985). A systematic analysis of students’ think aloud comments during a text-based explanatory modeling task would enable us to gain insight into the processing that students engage in during this task and uncover the mechanisms underlying the effects of the graphic organizer on reading and model construction. Thus, the present study sought to understand how the graphic organizer impacts students’ processing in the context of text-based explanatory modeling.

**The Current Study**

The current study had two main purposes: to test the effects of a graphic organizer scaffold on participants’ model construction and learning and to examine the processing that participants engaged in during the text-based explanatory modeling task, especially in relation to the presence or absence of the graphic organizer. The graphic organizer was intentionally designed to support participants in selecting model-relevant information from the texts, processing that information relative to the model they were asked to construct, and, to a lesser extent, reasoning about how the relevant information fits together, both within and across texts,
to construct the model. Two methods were used to make students’ processing visible: think-aloud protocols concurrent with the text-based explanatory modeling task and retrospective interviews focused on the completed models.

The design of the graphic organizer was based on the Idea Manager (McElhaney et al., 2012) and double entry charts (e.g., Schoenbach, et al., 2012) with the primary goal of supporting selection of relevant information and elaborative processing of this information. The graphic organizer included five double entry charts on one oversized sheet of paper. (See Appendix B for the complete graphic organizer.) Double entry charts are commonly used to focus attention on parts of a text that are relevant to the purposes for which the text is being read (e.g., Schoenbach, et al., 2012). One column is used to record information that is selected from the text and the second column explicitly asks students to reason about the information they selected. In the case of this study, there was a double entry chart for each text with a question in each of the two column headers. The first question “What do I notice in this text?” was intended to prompt participants to mindfully select information from the text. The second question “How do I think this helps me understand and explain what is causing the problem?” was intended to prompt participants to explain how and why the information they selected was relevant to the model they were asked to construct. Together these questions were intended to support students to select model-relevant information and analyze that information relative to the explanatory model. Pilot data suggested that this format was workable and encouraged the types of processing important to successful completion of the task (e.g., Ko et al., 2015).

A secondary goal of the graphic organizer was to support making connections within and across texts. To this end, the double entry charts for each of the five texts were presented side by side on a single sheet of paper, similar to the design of the Idea Manager. This design enabled
students to “see” all the selected information in a single space. However, unlike the Idea Manager, the instructions for the graphic organizer asked students to identify connections and draw lines/arrows between the information they recorded. They were asked to find at least five connections. Although the goal of these instructions was to support students in reasoning about how the information connects, both within and across texts, there was no explicit mention of within or across text connections.

It is also important to note that the graphic organizer was not designed to support multiple text use per se. Supports for multiple text use were present for both conditions in terms of the structure of the text set and the task instructions. The text set was designed so that each text in the set contributed information about particular elements and links but no text provided all the necessary information. For both graphic organizer present and absent conditions, the task instructions indicated that students should use information from multiple texts to construct their models.

The topic of inquiry was homeostasis, an NGSS Life Sciences Disciplinary Core Idea (Achieve, 2013). The specific phenomenon that we examined, sodium and water homeostasis, was selected because it relates to an interesting and surprising phenomenon—runner’s deaths due to hyponatremia or decreased blood sodium concentration. The “expert” explanatory model of sodium and water homeostasis involves three change processes: the process through which sodium and water balance is disrupted, the process through which sodium and water balance is restored, and the process that occurs if this balance is not restored, as shown in Figure 1. There are two types of model components shown in the figure: elements in rectangular boxes and links illustrated with arrows. The elements include initial and resulting states (e.g., balance between
sodium and water (E1) and imbalance (E4)) along with the intermediate elements that produce
the change. Links describe either temporal or causal relationships between elements.
Figure 1. Elements (in rectangular boxes) and links (unidirectional arrow) in the “expert” explanatory model of sodium and water homeostasis. In this figure, the model is broken up into three discrete change processes: disruption, restoration, and lack of restoration. As a result, E4 (imbalance) appears three times. The three change processes represented here comprise a single explanatory model in which E4 appears only once.
Sodium and water homeostasis is a dynamic process involving balanced intake and loss of sodium and water (E1). The first part of the model focuses on how this balance is disrupted (E1-E4). This process is complex in that balance can be disrupted in several ways. For example, you can drink too much water, lose salt through sweat, or both (E2). Any of these activities lead to a decreased concentration of sodium in the blood (E3). This causes sodium and water to become unbalanced (E4). The next part of the model focuses on how the body works to restore sodium and water balance (E4-E11). First, the body senses the imbalance and sends a signal to the brain (E5), which, in turn, lets the body know that it needs to take action to resolve the imbalance (E6). As a result, the body releases less of the hormone Vasopressin (E7), which causes the body to retain less water (E8) and produce more urine (E9). To support this process, doctors can also administer a medicine called Vaptans, which reduces the amount of Vasopressin taken up by the body (E7). These changes cause the concentration of sodium in the blood to go back up to normal levels (E10), which restores the balance of sodium and water in the body (E11). The final section of the model focuses on what happens if sodium and water balance is not restored (E4, E20-E22). If the individual continues to drink excess water and lose salt through sweat, the body may not be able to restore the balance of sodium and water (E20). This sustained imbalance will lead to symptoms (E21), such as nausea, and will eventually result in death (E22). The relationship between the components of the model and each of the texts in the text set are discussed in the Methods section.

Participants were provided with a text set and asked to use information from the texts to create an explanatory model of sodium and water homeostasis under two conditions of support: graphic organizer present or graphic organizer absent. In both conditions, participants were asked to engage in a concurrent think aloud during the text-based explanatory modeling task and, the
following day, in a retrospective interview followed by a learning application task. During the modeling task, participants were instructed to “describe what they were thinking and doing and why” while they read the texts and constructed their models. The comments they made constitute the think aloud protocol. During the retrospective interview, participants were asked to describe how they constructed their models.

Participants’ models were assessed for how many of the elements and links from the “expert” explanatory model they included (see Figure 1). To examine learning, participants’ ability to apply their understanding to a novel situation was assessed using a learning application task. The explanations participants provided during the learning application task were scored in terms of a rubric that examined the technical completeness of the explanation on each of the three topics addressed: runners’ physical condition, cause of the imbalance, and mechanism through which balance is restored.

Based on prior research, selection of relevant information and types of processing (Wolfe & Goldman, 2005; Goldman et al., 2012) were of particular interest. Selection of relevant information focused on the extent to which participants attended to information from the sections of the texts that contained information needed to construct the explanatory model. Types of processing focused on the ways that participants made sense of the information they attended to in the texts. Prior research has indicated that elaborative processing reflects deeper thinking about the information in the texts as compared to paraphrasing or restating the information (Wolfe & Goldman, 2005). Elaborative processing typically reflects reasoning about how the information fits together within and across texts. Of particular interest in this study were cross-text connections as they would assist students in understanding the relationships among elements mentioned in different texts.
Specifically, the following hypotheses were tested:

1. The explanatory models constructed in the presence of the graphic organizer were predicted to contain more of the relevant elements and links than those constructed in the absence of the graphic organizer. Likewise, the presence of the graphic organizer was predicted to result in better performance on the learning application task than the absence of the graphic organizer.

2. The presence of the graphic organizer was predicted to be associated with greater use of elaborative processing, especially of relevant information, than the absence of the graphic organizer. Likewise, the presence of the graphic organizer was predicted to be associated with greater use of elaborative processing, including connections within and across texts, than the absence of the graphic organizer.

The graphic organizer was intentionally designed to support the selection of relevant information and elaborative processing of that information. The graphic organizer also provided some support for within- and across-text synthesis. As such, a modest effect of the graphic organizer on elaborations that reflect synthesis was predicted. Although research examining the effects of these scaffolds is very limited, preliminary work suggests that similar scaffolds successfully engaged participants in forms of these targeted types of processing (e.g., Ko et al., 2015; Matuk et al., 2012). Additionally, these types of processing have been associated with more sophisticated performance on multiple text inquiry tasks (e.g., Wolfe & Goldman, 2005; Goldman et al., 2012).

3. The effects of the graphic organizer on model construction and learning application task performance were expected to be mediated by the selection of relevant information and elaborative processing of that information.
Given the conjecture that the graphic organizer would lead to more complete models and better performance on the learning application task because it would make it more likely that students would select relevant information and elaborate on that information, we hypothesized that the effects of the graphic organizer on each of the product measures would be mediated by the prevalence of elaborative processing of relevant information (Wiley et al., 2009; James et al., 2014; Wolfe & Goldman, 2005). In other words, the graphic organizer was expected to make it more likely that participants would select model-relevant information and analyze this information relative to the model and this type of processing would, in turn, lead to better models and learning.
METHODS

Design

This experimental study used a mixed design with the between-subjects variable of condition (presence or absence of the graphic organizer). Dependent measures derived from the text-based explanatory modeling task were the number of elements and links included in the model and learning application task performance. Dependent measures of processing were derived from the frequency of occurrence of four types of processing, selection of relevant versus non-relevant sections of the text, and cross-text synthesis.

Participants

Participants who were enrolled in four sections of a 9th grade Biology class taught by the same teacher were recruited from a public high school in a large, urban district. Fifty students consented to participate. Classes had covered homeostasis, but had not discussed the inquiry topic, sodium and water homeostasis, at the time of testing. Participants were randomly assigned to one of two conditions: graphic organizer present or graphic organizer absent. Two participants were removed from the analyses because they did not complete all the tasks involved in the study, leaving 24 with analyzable data in each group.

Materials

Explanatory model. The explanatory model relates to the explanation of sodium and water homeostasis described earlier (see Figure 1). This explanatory model was reviewed by a Nephrologist to confirm that it reflects current scientific understanding of the key elements and links involved in this phenomenon.
**Text Set.** The text set was designed to enable participants to construct the explanatory model of sodium and water homeostasis shown in Figure 1. Table I shows the distribution of the information that is relevant to the model across the different texts. Each text contributed information about particular elements and links but no single text provided all the information needed to construct the explanatory model of the phenomenon.

Table I was developed through a content analysis guided by the explanatory model depicted in Figure 1. Instances of information pertaining to the elements and links in the model were identified. If the text provided information relevant to a particular element or link, it was credited as discussed in that text. The sentences that conveyed information about elements and/or links were deemed relevant; the other sentences in the text were deemed not relevant to the model. Each visual representation was counted as one sentence. Both visual representations contained only relevant information. Appendix A contains all five texts and the mapping that resulted from this process. Importantly, Table I shows that texts varied with respect to the number of elements and links (columns 6 and 7) as well as which elements and links they discussed (column 8). Additionally, elements and links were mentioned with differential frequency across the text set, with concepts such as “sodium and water are not balanced” (E4) discussed in all five texts, but others such as “body releases less Vasopressin or Vaptans administered” (E7) discussed in only one text (Table I). There was only one link in the model, L21, that was not explicitly mentioned in any of the texts but could be inferred from text IV (Table I). To reiterate, no single text in the set gave students all the elements and links in the model and there was information in each text that was not relevant to the model. Thus, students needed to select relevant information from the texts and organize it to reflect the sequence of events involved in the maintenance, disruption, and restoration of balance. The expectation was
that elaborative processing of relevant information, within and across texts, would support the construction of more complete models and deeper understanding of the processes involved in maintaining, disrupting, and restoring homeostasis.
<table>
<thead>
<tr>
<th>Title</th>
<th>Source</th>
<th>Mode(s)</th>
<th># of Words</th>
<th>Lexile</th>
<th>Total # Elems</th>
<th>Total # Links</th>
<th>Elements and Links</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. When too much water hurts a runner</td>
<td>New York Times</td>
<td>Verbal Text</td>
<td>384</td>
<td>1370</td>
<td>6</td>
<td>2</td>
<td>Salt or water is consumed or lost (E2), Link (L2), Blood sodium concentration decreases (E3), Link (L3), Sodium and water are not balanced (E4), Body is unable to restore sodium and water balance (E20), Symptoms are experienced (E21), Death (E22)</td>
</tr>
<tr>
<td>II. Sodium and water: What's going on inside the body</td>
<td>Vander's Renal Physiology Textbook</td>
<td>Line Graph, Verbal Text</td>
<td>36, Graph</td>
<td>1720</td>
<td>6</td>
<td>4</td>
<td>Sodium and water are balanced (E1), Link (L1), Salt or water is consumed or lost (E2), Link (L2), Blood sodium concentration decreases (E3), Link (L3), Sodium and water are not balanced (E4), Blood sodium concentration increases (E10), Link (L10), Sodium and water balance is restored (E11)</td>
</tr>
<tr>
<td>III. Homeostasis</td>
<td>BSCS Biology Textbook</td>
<td>Verbal Text, Diagram</td>
<td>427, Diagram</td>
<td>1080</td>
<td>7</td>
<td>4</td>
<td>Sodium and water are balanced (E1), Sodium and water are not balanced (E4), Link (L4), Body sense imbalance (E5), Brain sends sign to body (E6), Link (L6), Sodium and water balance is restored (E11), Body is unable to restore sodium and water balance (E20), Link (L20), Death (E22)</td>
</tr>
<tr>
<td>IV. Salt: A world history</td>
<td>Food Science Book</td>
<td>Verbal Text</td>
<td>409</td>
<td>1190</td>
<td>5</td>
<td>2</td>
<td>Salt or water is consumed or lost (E2), Sodium and water are not balanced (E4), Link (L4), Body is unable to restore sodium and water balance (E20), Link (L20), Symptoms are experienced (E21), Death (E22)</td>
</tr>
<tr>
<td>V. Vaptans for the treatment of hyponatremia</td>
<td>Scientific Research Journal</td>
<td>Verbal Text</td>
<td>199</td>
<td>1190</td>
<td>7</td>
<td>6</td>
<td>Blood sodium concentration decreases (E3), Link (L3), Sodium and water are not balanced (E4), Link (L4), Body senses imbalance (E5), Link (L5), Body releases less Vasopressin (E7), Link (L7), Body retains less water (E8), Link (L8), Body produces more urine (E9), Link (L9), Blood sodium concentration increases (E10)</td>
</tr>
</tbody>
</table>
**Graphic Organizer.** The graphic organizer was designed to support the selection of relevant information and elaborative processing of the selected information. The graphic organizer also provided limited support for reasoning about how the information connects, both within and across texts. The graphic organizer included five double entry charts, one for each text (see Figure 2 for specific prompts). In the instructions, participants were asked to draw a line between pieces of information that they thought were related to one another. The instructions also said that they should try and find at least five connections. Students’ inscriptions on the graphic organizer were somewhat limited and their think aloud comments while completing the graphic organizer repeated and went beyond these inscriptions. As a result, inscriptions on the graphic organizer were not extensively analyzed.

<table>
<thead>
<tr>
<th>Text:</th>
<th>What do I notice in this text?</th>
<th>How do I think this helps me understand and explain what is causing the problem?</th>
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*Figure 2. One of the five double entry charts in the graphic organizer*
Tasks

The study consisted of three different focal activities: text-based explanatory modeling with concurrent think aloud, retrospective interview, and learning application.

Text-based explanatory modeling with concurrent think aloud. During the text-based explanatory modeling task, participants read the texts and constructed a model. They were instructed to “use information from the texts to create a model that explains how the body works to maintain the balance of sodium and water and what happens when this balance is disrupted”. The order of activities was not constrained. As a result, some participants read the texts first and then made a model, while others made a model while reading. The task instructions also provided background information on science models—indicating that scientists create models to help them understand and explain the problems that they study (Appendix C). This background information was adapted from materials developed by the IQWST (Investigating and Questioning our World through Science and Technology) project (Krajcik et al., 2008). Additionally, the instructions equated the task to a jigsaw puzzle, which was adapted from instructions used in a previous study of students’ processing of multiple texts (Goldman et al., 2012). During the reading and model construction, participants were instructed to “describe what they were thinking and doing and why.” They were also told that they would be reminded to think aloud after one minute of silence. (See Appendix D for specific instructions.) The think aloud protocol was intended to elicit information about the processing that participants engaged in during the text-based explanatory modeling task.

Additionally, participants in the graphic organizer present condition were also provided with the graphic organizer and instructed to use it while reading and constructing their model (See Appendix B for specific instructions.)
**Retrospective interview.** The retrospective interview was intended to elicit additional information about the modeling process that may not have been revealed during the think aloud. Participants watched a recording of their modeling process. Playback was paused to ask a series of questions about each “part” of the model. “Part” was defined as a single visual element (e.g., object, arrow, line, etc.) or verbal clause that reflected a unique element. Questions focused on what each part of the model showed, where the information came from, and what each part added to the model. (See Appendix E for specific instructions and questions.) Students’ responses during the retrospective interview mostly repeated information provided during the explanatory modeling task and concurrent think aloud, rather than adding metacognitive reflections on their reading and modeling process. Based on these initial analyses showing redundancy with information from the concurrent think-aloud, further analyses of the retrospective interviews were not conducted and no additional data on them is discussed herein.

**Learning application task.** The learning application task was designed to assess participant’s ability to apply their understanding of sodium and water homeostasis, as constructed during the text-based inquiry and modeling task, to a novel situation. In this task, participants were asked: 1) what would happen to a runner’s physical condition by the end of a long run on a 95°F day if the runner forgot to bring a water bottle along and why they thought that, 2) what the runner’s body would need to do to restore balance and why. (See Appendix F for specific instructions.)

**Procedure**

Participants worked with the researcher one-on-one in a quiet room for two, 50- minute sessions. Session 1 was devoted to the text-based explanatory modeling task with concurrent think aloud. Session 2 included the retrospective interview and learning application task.
Session 1. After completing informed consent, participants were instructed to read the first text in the text set to familiarize them with the problem. The researcher then read the think aloud instructions and provided the modeling task instructions. As part of the think aloud task instructions, the researcher demonstrated the task using an unrelated text about the circulatory system to construct an explanatory model while thinking aloud (Appendix G). This text was adapted from the text used in Chi, de Leeuw, Chiu, and Lavancher (1994) in that a relevant diagram was added. This demonstration included two instances of thinking aloud about each of the following: selecting information from the text, analyzing information, and synthesizing information to construct the model. Both verbal text and visual text were used to construct the model and the model that was constructed included words as well as diagrams. For participants in the graphic organizer present condition only, the researcher then provided the graphic organizer and read the instructions. Next, participants were given the other four texts in the text set, a LiveScribe pen, and paper. Participants were then instructed to begin the text-based explanatory modeling task with concurrent think aloud. Participants had the entire class period to complete the task. The session was video recorded. The camera was positioned behind the participant’s shoulder to capture the texts and model along with their vocalizations. The model construction and corresponding audio were recorded using the LiveScribe pen.

Session 2. The researcher read the retrospective interview instructions. The recording of the student’s model construction, made using the LiveScribe pen, was then played on a laptop computer. The researcher paused the recording each time the student completed a new element or link to the model or revised an existing element or link. Sections of the recording that did not pertain to model construction (e.g., reading the texts out loud) were skipped. For each new or revised element or link, the researcher asked the participant each of the interview questions.
After the entire model had been discussed, participants completed the learning application task. The researcher read the instructions and asked the student each of the questions. Participants had the entire class period to complete the tasks. The session was video recorded. The camera was again positioned behind the participant’s shoulder.

Analytic Approach

Data sources. The data sources include the text-based explanatory modeling task with concurrent think aloud video recording, the retrospective interview video recording, the learning application task video recording, and the completed explanatory models.

Preparation of transcripts for coding. The text-based explanatory modeling task and concurrent think aloud, retrospective interview, and learning application task video recordings were transcribed using InqScribe. The transcripts included information about where participants were gesturing (largely pointing) on the texts or their models based on the video recordings. The use of the video thus made it possible to coordinate references in speech to the texts or student model, allowing incorporation of deictic references.

Coding of the explanatory models. The models that participants constructed were scored against the expert model (see Figure 1) to determine which elements and which links were included. Appendix H provides definitions and examples of model elements and links. Once identified, each element was coded for accuracy. Accuracy reflected whether the element was scientifically normative. Each student was assigned a score for number of accurate elements (max = 14) and a score for number of links (max = 12). Links could have been inaccurate (e.g., reversed relationship), but this did not occur in the data. One higher and one lower scoring model is included in Appendix I to illustrate the application of this coding. To establish interrater reliability, 21% of the models were scored by a second coder. Interrater reliability was 83% for
model elements and 74% for model links. Interrater reliability was 96% for element accuracy. Disagreements were resolved through discussion.

Coding of the transcripts from the learning application task. Transcripts of responses to the two interview questions were evaluated with respect to three topics: the runners' condition, the cause of the condition, and the mechanism through which balance is restored. The response on each topic was evaluated with a rubric reflecting technical completeness of the response, provided in Table II. For example, incorrect responses received the lowest score. Responses that were connected to salt and water imbalance received higher rubric scores than general responses that were not. Responses that were connected to salt and water imbalance and provided detail about the condition or described the causal chain received the highest score. This coding produced a score for each of the topics: condition (max = 3), cause, (max = 3), and restore (max = 4). Scores for each topic were also combined to produce an overall learning application task score (max = 10). To establish interrater reliability, 21% of the transcripts were examined by a second coder. Interrater reliability was 90%. Disagreements were resolved through discussion. One higher and one lower scoring learning application task is included in Appendix J to illustrate the application of this coding.
<table>
<thead>
<tr>
<th>Topic</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Condition</td>
<td>No info or only incorrect info about physical condition.</td>
<td>Mentions condition (e.g., tired, sick) that is not connected to salt and water imbalance.</td>
<td>Mentions condition (e.g., dehydrated, thirsty) connected to salt/water imbalance.</td>
<td>Mentions condition related to salt/water imbalance and provides details about condition (e.g., no homeostasis)</td>
<td></td>
</tr>
<tr>
<td>Cause</td>
<td>No info or only incorrect info about cause.</td>
<td>Mentions cause (e.g., heat, exercise) that is not connected to salt and water imbalance.</td>
<td>Mentions cause (e.g., didn’t drink water, sweating) that is connected to salt and water imbalance.</td>
<td>Mentions cause that is related to salt and water imbalance and describes causal chain (e.g., sweating causes salt loss).</td>
<td></td>
</tr>
<tr>
<td>Restore Balance</td>
<td>No info or only incorrect info about actions to restore balance.</td>
<td>Mentions action to restore balance (e.g., rest) that is not connected to salt and water imbalance.</td>
<td>Mentions action to restore balance (e.g., drink water) that is connected to salt and water imbalance.</td>
<td>Mentions internal mechanism (e.g., release vasopressin) that would restore balance.</td>
<td>Mentions internal mechanism (e.g., release vasopressin) that would restore balance, describes causal chain (e.g., causes body to retain water).</td>
</tr>
</tbody>
</table>

**Coding of the transcripts from the explanatory modeling task with concurrent think aloud.**

Transcripts of the explanatory modeling task with concurrent think aloud were created using the video recording of the session. They were parsed into utterances, defined as bursts of speech between pauses, and thus could reflect single or multiple clause sentences. Utterances were indexed with respect to which part of which text each referenced. Utterances were coded with respect to the type of processing reflected in the comment.

**Indexing utterances to text sections.** Decisions about which section(s) of which text(s) an utterance referred to were based on semantic overlap, explicit verbal pointers (e.g., this sentence reminds me...) or deictic gestures (e.g., pointing). If an utterance could not be clearly linked to a
particular section of text, no code was applied. This occurred for less than 5% of the utterances across all subjects. A transcript excerpt with utterances indexed to text sections is provided in Appendix K. To establish interrater reliability, 21% of the transcripts were examined by a second coder. Each utterance was coded for which section of which text it referred to. Interrater reliability was 78% for which section of which text utterances referred to. Disagreements were resolved through discussion.

*Types of processing.* Four major categories of processing codes were used to classify each utterance: restatement, paraphrase/summary, elaboration, and evaluation. Restatements repeat a section of the text verbatim. Paraphrase/summaries repeat the gist of a section of the text without adding additional information. Elaborations create new knowledge that serves the purpose of improving understanding of the text. Evaluations convey a judgment about an aspect of the text or the reader. Examples of each type of processing are provided in Appendix L. Think aloud utterances were not coded for the elements and links that they reflected. Some multiple clause utterances reflected multiple types of processing, in which case multiple codes were applied to the utterance. To establish interrater reliability, 21% of the transcripts were examined by a second coder. Each utterance was coded for the type(s) of processing it reflected. Interrater reliability for types of processing was 82%. Disagreements were resolved through discussion.

Each utterance was also coded as model relevant or not. Relevance coding relied on the content analyses of the text set (Appendix A). If the section of text to which an utterance was indexed had been tagged as model relevant in the content analysis, the utterance was classified as relevant. If the section of text to which an utterance was indexed had been tagged as not relevant or the utterance could not be clearly linked to a particular section of a text, the utterance was
classified as non-relevant. This was done so that it was possible to determine what type of processing was being done on which type of information from the texts—model relevant or non-relevant—for each utterance. Examples of this coding are provided in Appendix K.

Elaborations were coded for two additional features: accuracy and cross-text synthesis. Accuracy reflected whether the added information was scientifically normative. Inaccurate elaborations were excluded from further analyses. In the graphic organizer present condition, a mean of 2.6 elaboration utterances, or 14% of elaborations, stated scientifically incorrect information; the mean for scientifically incorrect information was 4.4, or 29% of elaborations, in the graphic organizer absent condition. To establish interrater reliability, 21% of the transcripts were examined by a second coder. The similarity in these rates indicates that excluding inaccurate elaborations did not differentially impact the two conditions. Interrater reliability for accuracy was 91%. Disagreements were resolved through discussion.

If an elaboration reflected integration of information from more than one text, it was additionally tagged as cross-text synthesis. Utterances that explicitly mentioned information from multiple texts and connected that information semantically were coded as cross-text synthesis. For example, the following utterance would be coded as cross-text synthesis: “The symptoms for lack of salt (Text 4) reminds me of umm...homeostasis because like you get a headache and you start feeling nausea and everything (Text 1), which is the same thing that salt has (Text 4).” Not coded as cross-text synthesis were (1) utterances that provided a list of ideas from multiple texts in sequence but did not connect them semantically; and (2) mentions of an element that appeared in multiple texts but without connecting what was said in one text with what was said about the element in other text(s). To establish interrater reliability, 21% of the
transcripts were examined by a second coder. Interrater reliability for cross-text synthesis was 80%. Disagreements were resolved through discussion.

**Summary of Dependent Measures**

Thus, for each participant, total frequency of think aloud utterances was calculated as well as ten additional scores: eight scores resulted from the frequencies of each of the four types of processing (restatement, paraphrase/summary, elaboration, evaluation) crossed with whether the information was relevant or not relevant to the model. Two additional scores were created by indicating the frequency of elaborations that reflected cross-text synthesis, yielding a total of four elaboration scores (elaboration relevant synthesis, elaboration relevant no synthesis, elaboration not relevant synthesis, and elaboration not relevant no synthesis).
RESULTS

Preliminary analyses

Preliminary analyses were conducted to test for the comparability of the samples that comprised the two levels of the between-subjects variable of condition (graphic organizer present, graphic organizer absent). Teacher-provided ratings of quality of class performance (low, medium, high) were submitted to a chi-square test to examine whether there was a relationship to condition. In the graphic organizer present condition, 17% were rated low, 33% were rated medium, and 50% were rated high. In the graphic organizer absent condition, 29% were rated low, 42% were rated medium, and 29% were rated high. Results indicated that there were no significant relationships between condition and performance ratings; \( X^2(2, N = 48) = 2.38, p = .31 \). As a result, class performance was not included in subsequent analyses.

In addition, during the modeling task, the researcher noted that some participants read the texts and then constructed the model whereas other participants engaged in modeling and reading at the same time. A chi-square test was conducted to examine whether a relationship existed between condition (graphic organizer present, graphic organizer absent) and approach to the task. In the graphic organizer present condition, 92% read first and 8% modeled while reading. In the graphic organizer absent condition, 83% read first and 17% modeled while reading. The chi-square test indicated no significant relationship between condition and task approach; \( X^2(1, N = 48) = .76, p = .38 \). Accordingly, approach to the task was not considered further in the analyses. Additionally, a preliminary examination of which and how many texts were used indicated that all students used multiple texts, consistent with the task instructions.

The results are organized to address each of the research questions sequentially. Effects were considered statistically reliable at the \( p < .05 \) level. Effect sizes between groups were estimated using Cohen’s \( d \) (Cohen, 1977), with a value of .20 considered small, .50 considered
moderate, and .80 considered large. Within group effect sizes were estimated with partial eta squared (Cohen, 1973), with a value of .01 considered small, .09 considered moderate, and .25 considered large.

Effects of the graphic organizer on model construction and learning application task

Analyses were conducted to examine the effect of the presence of the graphic organizer on two measures of model construction—number of elements, number of links—and learning application task performance. The presence of the graphic organizer was predicted to result in more complete models, with respect to the number of elements and links included, and better performance on the learning application task than the absence of the graphic organizer.

Model construction. Two one-way, between-subjects ANOVAs were conducted: one for number of elements and a second for number of links. There was a significant graphic organizer effect for number of elements, but not for number of links. For elements, participants in the graphic organizer present condition included significantly more elements in their models ($M = 6.2$, $SD = 2.1$) than participants in the graphic organizer absent condition ($M = 4.8$, $SD = 2.0$); $F(1, 46) = 5.5$, $p < .05$, $d = .68$. Participants in both conditions produced an average of just under two links: graphic organizer present $M = 1.9$ ($SD = 1.3$) and graphic organizer absent $M = 1.8$ ($SD = 1.1$); $F(1, 46) = .05$, $p > .10$.

Table III shows the proportion of students in each condition (graphic organizer present, graphic organizer absent) that included each of the elements and links in the “expert” explanatory model of the phenomenon in the model they created. An element or link was considered differentially included between conditions if there was a difference of .13 or greater. More students in the graphic organizer condition included the main elements that are needed to explain the phenomenon: sodium and water are balanced (E1), too much water is consumed or
salt is lost (E2) and sodium and water balance is restored (E11). Additionally, more students in
the graphic organizer condition included two elements and one link related to the general
feedback mechanism involved in homeostasis: the body senses the imbalance and sends a signal
to brain (E5), the brain sends a signal to the body telling it to take action (E6), and the temporal
link between those elements (L5). It is also interesting to note that the element mentioned in all
five texts was included by 88% of the participants regardless of condition, perhaps due to
repetition of this element.
Table III

Proportion of participants including each element and link by condition

<table>
<thead>
<tr>
<th>Text(s) that discuss</th>
<th>Elements and Links</th>
<th>Graphic Organizer Present</th>
<th>Graphic Organizer Absent</th>
</tr>
</thead>
<tbody>
<tr>
<td>II, III</td>
<td>Sodium and water are balanced (E1)</td>
<td>0.75</td>
<td>0.5</td>
</tr>
<tr>
<td>II</td>
<td>Temporal link (L1)</td>
<td>0</td>
<td>0.04</td>
</tr>
<tr>
<td>I, II, IV</td>
<td>Water is consumed or salt is lost (E2)</td>
<td>0.96</td>
<td>0.79</td>
</tr>
<tr>
<td>I, II</td>
<td>Causal link (L2)</td>
<td>0.46</td>
<td>0.42</td>
</tr>
<tr>
<td>I, II, V</td>
<td>Blood sodium concentration decreases (E3)</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>I, II, V</td>
<td>Causal link (L3)</td>
<td>0.04</td>
<td>0.08</td>
</tr>
<tr>
<td>I, II, III, IV, V</td>
<td>Sodium and water are not balanced (E4)</td>
<td>0.88</td>
<td>0.88</td>
</tr>
<tr>
<td>III, IV, V</td>
<td>Causal link (L4)</td>
<td>0.42</td>
<td>0.46</td>
</tr>
<tr>
<td>III, V</td>
<td>Body senses imbalance and sends signal to brain (E5)</td>
<td>0.42</td>
<td>0.13</td>
</tr>
<tr>
<td>V</td>
<td>Causal link (L5)</td>
<td>0.13</td>
<td>0</td>
</tr>
<tr>
<td>III</td>
<td>Brain sends signal to body to take action (E6)</td>
<td>0.5</td>
<td>0.25</td>
</tr>
<tr>
<td>III</td>
<td>Causal link (L6)</td>
<td>0.21</td>
<td>0.13</td>
</tr>
<tr>
<td>V</td>
<td>Body releases less Vasopressin/Vaptans administered (E7)</td>
<td>0.54</td>
<td>0.5</td>
</tr>
<tr>
<td>V</td>
<td>Causal link (L7)</td>
<td>0.38</td>
<td>0.33</td>
</tr>
<tr>
<td>V</td>
<td>Body retains less water (E8)</td>
<td>0.46</td>
<td>0.38</td>
</tr>
<tr>
<td>V</td>
<td>Temporal link (L8)</td>
<td>0.04</td>
<td>0</td>
</tr>
<tr>
<td>V</td>
<td>Body produces more urine (E9)</td>
<td>0.29</td>
<td>0.33</td>
</tr>
<tr>
<td>V</td>
<td>Causal link (L9)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>II, V</td>
<td>Blood sodium concentration increases (E10)</td>
<td>0.08</td>
<td>0.04</td>
</tr>
<tr>
<td>II</td>
<td>Causal link (L10)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>II, III</td>
<td>Sodium and water balance is restored (E11)</td>
<td>0.25</td>
<td>0.04</td>
</tr>
<tr>
<td>I, III, IV</td>
<td>Body is unable to restore sodium and water balance (E20)</td>
<td>0.13</td>
<td>0.08</td>
</tr>
<tr>
<td>III, IV</td>
<td>Causal link (L20)</td>
<td>0.04</td>
<td>0.08</td>
</tr>
<tr>
<td>I, IV</td>
<td>Symptoms are experienced (E21)</td>
<td>0.5</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>Temporal link (L21)</td>
<td>0</td>
<td>0.08</td>
</tr>
<tr>
<td>I, III, IV</td>
<td>Death (E22)</td>
<td>0.33</td>
<td>0.38</td>
</tr>
</tbody>
</table>

**Learning application task.** Participants in the graphic organizer present condition performed significantly better ($M = 8.1$, $SD = 1.5$) than those in the graphic organizer absent condition ($M = 6.7$, $SD = 1.3$); $F(1, 46) = 13.0$, $p = .001$, $d = 1.0$. Of the three components of this score, additional between-subjects ANOVAs indicated that this pattern was significant for two of the three subscores. Specifically, participants in the graphic organizer present condition scored
higher on cause of the imbalance ($M = 2.6, SD = .50$) than those in the graphic organizer absent condition ($M = 2.0, SD = .55$); $F(1, 46) = 14.9, p < .001, d = 1.1$, as well as the mechanism through which balance is restored, with participants in the graphic organizer present condition scoring significantly better ($M = 3.0, SD = .96$) than participants in the graphic organizer absent condition ($M = 2.5, SD = .83$); $F(1, 46) = 4.4, p < .05, d = .56$.

**Effects of the graphic organizer on processing**

Analyses were conducted to examine the effects of the presence of the graphic organizer on students’ processing. The presence of the graphic organizer was predicted to be associated with greater use of elaborative processing, especially of relevant information, than the absence of the graphic organizer. The distributions of utterances across the various types of processing and the number of participants with a greater than zero value in each cell are shown in Table IV. As is evident in the table, the frequencies associated with restatements and evaluations were virtually identical across conditions, and although most participants in each condition made at least one of each, the frequencies were low and the standard deviations were greater than the means. Note that these low frequencies were distributed relatively equally across relevant and not relevant sections of the text. For these reasons, these two processing types were excluded from subsequent analyses.
Table IV  
**Mean Frequencies of Utterances for Each Type of Processing by Condition**

<table>
<thead>
<tr>
<th>Graphic Organizer</th>
<th>M (# of Participants with &gt; 0)</th>
<th>SD</th>
<th>Graphic Organizer</th>
<th>M (# of Participants with &gt; 0)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present Condition</td>
<td></td>
<td></td>
<td>Absent Condition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elaboration³</td>
<td>16.3 (24)</td>
<td>10.2</td>
<td>Elaboration³</td>
<td>10.6 (23)</td>
<td>10.0</td>
</tr>
<tr>
<td>Relevant Synthesis</td>
<td>3.3 (17)</td>
<td>3.7</td>
<td>Relevant Synthesis</td>
<td>1.4 (8)</td>
<td>2.5</td>
</tr>
<tr>
<td>Relevant No Syn</td>
<td>9.2 (23)</td>
<td>6.8</td>
<td>Relevant No Syn</td>
<td>4.6 (19)</td>
<td>6.0</td>
</tr>
<tr>
<td>Not Relevant Syn</td>
<td>.21 (2)</td>
<td>.83</td>
<td>Not Relevant Syn</td>
<td>.08 (2)</td>
<td>.28</td>
</tr>
<tr>
<td>Not Relevant No Syn</td>
<td>3.7 (20)</td>
<td>2.7</td>
<td>Not Relevant No Syn</td>
<td>4.5 (19)</td>
<td>4.4</td>
</tr>
<tr>
<td>Paraphrase/Summary</td>
<td>16.3 (24)</td>
<td>7.5</td>
<td>Paraphrase/Summary</td>
<td>16.8 (23)</td>
<td>12.1</td>
</tr>
<tr>
<td>Relevant</td>
<td>7.8 (23)</td>
<td>4.2</td>
<td>Relevant</td>
<td>7.5 (21)</td>
<td>6.5</td>
</tr>
<tr>
<td>Not Relevant</td>
<td>8.4 (24)</td>
<td>4.6</td>
<td>Not Relevant</td>
<td>9.3 (23)</td>
<td>6.0</td>
</tr>
<tr>
<td>Restatement</td>
<td>2.7 (19)</td>
<td>4.2</td>
<td>Restatement</td>
<td>2.5 (10)</td>
<td>3.7</td>
</tr>
<tr>
<td>Evaluation</td>
<td>4.8 (20)</td>
<td>5.8</td>
<td>Evaluation</td>
<td>4.9 (19)</td>
<td>5.3</td>
</tr>
</tbody>
</table>

³Frequencies are for correct elaborations only. In the graphic organizer present condition, a mean of 2.6 elaboration utterances stated scientifically incorrect information; the mean for scientifically incorrect information was 4.4 in the graphic organizer absent condition.

A preliminary analysis indicated that the total frequency of utterances produced by participants in each condition was not statistically different: graphic organizer present condition $M = 42.7 \ (SD = 18.1)$ and graphic organizer absent condition $M = 39.2 \ (SD = 24.6)$; $F(1, 46) = .32, p > .10$. Therefore, a mixed ANOVA with the between-subjects variable of condition (graphic organizer present, graphic organizer absent) and two within-subjects variables—type of processing (elaboration, paraphrase/summary) and text section selected (relevant, not relevant)—was conducted using the frequencies as the dependent measure. There was a significant main effect of relevance ($F(1, 46) = 10.0, p < .01, \eta_p^2 = .18$), and a main effect of type of processing although it exceeded conventional significance levels ($F(1, 46) = 2.8, \ p = .10, \eta_p^2 = .06$). The main effect of condition was not significant; $F(1, 46) = 1.3, p > .10$. However, the predicted three-way interaction of condition, type of processing, and relevance was significant ($F(1, 46) = 6.2, p < .05, \eta_p^2 = .12$), as were the two-way interactions of type of processing by relevance ($F(1,
The two-way interaction of condition by processing exceeded conventional significance levels $(F(1,46) = 2.9, p = .09, \eta^2 = .06)$. Simple effects tests with a Bonferroni correction were conducted to examine the three-way interaction. For the between conditions effects, the only significant comparison was for elaborative processing of relevant information, $M = 12.5, SD = 9.2$ in the graphic organizer present condition versus $M = 6.0, SD = 6.8$ in the graphic organizer absent condition; $F(1, 46) = 7.7, p < .01, d = .80$. No other comparisons in this interaction were significant. Thus, the graphic organizer did not differentially impact paraphrase/summary of relevant and non-relevant information nor elaboration of non-relevant information. This suggests that the graphic organizer had the intended effect of prompting students to select relevant information and elaboratively process this information relative to the model.

The simple effects tests within each condition further support this conclusion regarding the effects of the graphic organizer on processing. In the graphic organizer present condition, elaborative processing was about three times as likely for relevant information ($M = 12.5, SD = 9.2$) compared to non-relevant information ($M = 3.8, SD = 2.6$); $F(1,46) = 32.9, p < .001$. However, paraphrasing was equally likely for relevant ($M = 7.8, SD = 4.2$) and non-relevant ($M = 8.4, SD = 4.6$) information. The patterns within the graphic organizer absent condition differed from those within the graphic organizer present condition. Elaborative processing was equally likely for relevant ($M = 6.0, SD = 6.8$) and non-relevant ($M = 4.6, SD = 4.4$) information. Paraphrase/summary processing was significantly more frequent for non-relevant ($M = 9.3, SD = 6.0$) versus relevant ($M = 7.5, SD = 6.5$) information, $F(1,46) = 4.3, p < .05$. This within conditions pattern is further evidence that the graphic organizer encouraged selection and deeper
processing of model-relevant information. Indeed, in its absence, participants tended to engage in more surface-level processing of information that was less relevant to the model.

**Effects of the graphic organizer on cross-text synthesis**

The presence of the graphic organizer was predicted to have a modest effect on elaborations that reflect cross-text synthesis. Cross-text synthesis was only possible in utterances coded as elaborative processing. Thus, the analysis examining the effects of the graphic organizer on cross-text synthesis was conducted only for the subset of utterances that were coded as elaborations. Furthermore, given that there were significant frequency differences for elaborations related to condition and relevance, the cross-text synthesis analysis was conducted on proportions rather than frequencies. As indicated earlier, four proportions were calculated based on the frequency of elaborations that reflected two within-subjects variables: text section selected (relevant, not relevant) and cross-text synthesis (present, absent).

A mixed ANOVA with the between-subjects variable of condition (graphic organizer present, graphic organizer absent) and two within-subjects factors—text section selected (relevant, not relevant) and cross-text synthesis (present, absent)—was conducted. There was a significant main effect of relevance \( F(1,46) = 15.3, p < .001, \eta^2_p = .25 \), a significant main effect of cross-text synthesis \( F(1,46) = 88.9, p < .001, \eta^2_p = .66 \), and a significant two-way interaction of condition by relevance \( F(1,46) = 11.5, p = .001, \eta^2_p = .20 \). The three-way interaction of condition, relevance, and synthesis was not significant \( F(1,46) = 2.1, p = .15, \eta^2_p = .04 \). The two-way interactions of condition by synthesis and relevance by synthesis were not significant. The proportion of elaborations that reflected cross-text synthesis was low in both the graphic organizer present \( (M = .22, SD = .23) \) and graphic organizer absent \( (M = .12, SD = .21) \) condition. Indeed, the significant effect of cross-text synthesis indicates that not making cross-
text connections was more likely than making them. Thus, this analysis on proportions of elaborations reinforces the relevance effect related to condition reported above in the frequency analyses and indicates no significant effect of the graphic organizer on cross-text synthesis. Indeed, cross-text synthesis was infrequent, regardless of condition.

**Relationships between condition, processing, and product measures**

Correlation analyses were conducted to provide an initial test of whether it would be fruitful to explore the mediational hypothesis. The effects of the graphic organizer on model construction and learning application task performance were expected to be mediated by the selection of relevant information and elaborative processing of that information. Table V provides the correlation coefficients that resulted from calculating Pearson correlations for the processing variables and product measures. As is evident in the table, elaboration of relevant information, with and without cross-text synthesis, were significantly related to number of elements and learning application task performance. Furthermore, the other processing types were not significantly related to number of elements and learning application task performance. The pattern of correlations for links was different from the other product measures in that they were, in general, much weaker, which is not surprising given the low levels of inclusion of links. Based on the pattern of correlations in Table V, the mediation analyses were only conducted for the dependent measures number of elements and learning application task performance. Frequency of elaboration of relevant information was used as the mediator, based on the similarity of the correlations for elaboration of relevant information with and without synthesis.
Table V
*Correlations between Types of Processing, Model Construction, and Learning Application Task Performance*

<table>
<thead>
<tr>
<th></th>
<th>Model: # of Elements</th>
<th>Model: # of Links</th>
<th>Learning Application Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elaboration (Synthesis)- Relevant</td>
<td>.59**</td>
<td>.27*</td>
<td>.41*</td>
</tr>
<tr>
<td>Elaboration (Synthesis)- Not Relevant</td>
<td>.22</td>
<td>.02</td>
<td>.10</td>
</tr>
<tr>
<td>Elaboration (No Synthesis)- Relevant</td>
<td>.60**</td>
<td>.17</td>
<td>.41*</td>
</tr>
<tr>
<td>Elaboration (No Synthesis)- Not Relevant</td>
<td>.26</td>
<td>.28*</td>
<td>-.08</td>
</tr>
<tr>
<td>Paraphrase/Summary- Relevant</td>
<td>-.04</td>
<td>-.12</td>
<td>-.08</td>
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<tr>
<td>Paraphrase/Summary- Not Relevant</td>
<td>-.22</td>
<td>-.27</td>
<td>-.16</td>
</tr>
</tbody>
</table>

*aPearson correlations were calculated. **p < .001; *p = .05.*

Mediation analyses were conducted using the PROCESS macro for SPSS, which uses a bootstrapping method to examine the effect of a mediating variable on the relationship between an independent variable and dependent variable (Hayes, 2013). Results are based on 1000 bootstrapped samples. The mediation models that result from this analysis are shown in figures 3a (number of elements) and 3b (learning application task performance). There are five outputs that are important to look at in the mediation analysis, including the regression coefficients \( b \) for the relationships between condition and mediator, mediator and product measure, and condition and product measure. The unstandardized regression coefficient \( b \) provides an indicator of the amount of variance in the dependent variable explained by the predictor variable. As the \( b \) values next to each arrow in the figures indicate, each of the predictor variables in the mediation models significantly predicts each of the dependent variables. Additionally, the mediation analysis produces a regression coefficient \( b \) for the entire model, which indicates the amount of variance accounted for when you take the mediator into account. The significance test for the mediation effect involves the 95% confidence interval (“95% CI”). If the 95% confidence interval (“95% CI”) does not include zero there is a significant mediation effect (e.g., a 95% CI
of .25 to 1.7 indicates a significant mediation effect). If the 95% CI includes zero there is not a significant mediation effect. A significant mediation effect means that condition has a strong indirect effect on the product measure through the mediator. As the $b$ value and 95% CI below each figure indicate, there is a significant mediation effect of elaborative processing of relevant information on the relationship between condition and number of elements, $b = 1.0$, 95% CI [.37, 1.89] and the relationship between condition and learning application task performance, $b = .39$, 95% CI [.10, .90]. Thus, the results indicate a significant mediation effect of elaborative processing of relevant information on the relationships between condition and each of these product measures. In other words, these models show that having a graphic organizer made it more likely that participants would engage in elaborative processing of relevant information, which, in turn, led to more complete models, with respect to number of elements included, and better learning application task performance.

**Figure 3.** Relationships between condition and product measures mediated by number of elaborations on relevant information. The values reflect the regression coefficient ($b$) for each relationship represented in the figure. Below each figure, the regression coefficient ($b$) and 95% confidence interval for the mediation effect of elaboration of relevant information on the relationship between condition and the product measure is presented.
DISCUSSION

The current study examined the effects of a graphic organizer scaffold on model construction and performance on a learning application task in the context of text-based explanatory modeling. Importantly, this work also focused on uncovering the processing involved in this task, examining the ways that the graphic organizer impacted processing, and analyzing the extent to which processing accounted for the effects of the scaffold on model construction and learning in this context. Consistent with predictions, the results indicate a positive impact of the graphic organizer on both model construction, with respect to the number of elements included, and learning, as measured by the learning application task. Furthermore, the use of think-aloud methodology provided access to the processing that occurred during the text-based explanatory modeling task. Following from the second hypothesis, the graphic organizer appeared to encourage deeper forms of processing, namely elaborative processing of relevant information; effects on cross-text synthesis were not evident in the present data. Without the graphic organizer, participants tended to engage in more surface-level processing of information that was less relevant to the model. The third hypothesis, that elaborative processing of relevant information mediated the effects of the graphic organizer on model construction and learning, was also supported. Indeed, consistent with predictions, results suggest that the graphic organizer led to more elaborative processing of relevant information which, in turn, led to better model construction, with respect to the number of element included, and performance on the learning task. In other words, it was not the graphic organizer itself, but the productive forms of processing it encouraged—elaborative processing of relevant information—that led to better model construction and learning.
The results of the current study are consistent with and build upon prior research on text-based inquiry. Consistent with prior research, the graphic organizer led to significantly better model construction, with respect to number of elements included, and learning (e.g., Ko et al., 2015; Matuk et al., 2012). Consistent with prior research, we found that particular types of processing, namely elaborative processing of relevant information, were related to successful model construction and learning for adolescent science learners (e.g., Wolfe & Goldman, 2005; Goldman et al., 2012). The current study also goes beyond this work by demonstrating that elaborative processing of relevant information mediated the effects of the graphic organizer on model construction, with respect to number of elements included, and learning. Importantly, this suggests that it is not the scaffold itself, but rather the productive forms of processing that it encourages—elaborative processing of relevant information—that lead to better model construction and learning. Uncovering the types of processing that underlie successful text-based explanatory modeling and how these processes relate to successful model construction and learning enables us to begin to understand how to effectively support students in this important but challenging task. The present findings suggest that learning environments that seek to effectively engage students in the authentic scientific practice of text-based explanatory modeling should incorporate scaffolds, such as graphic organizers, that promote these productive forms of processing. Thus, this work contributes to a deeper understanding of the types of processing that underlie text-based explanatory modeling, the relationships between processing and successful explanatory modeling and learning, and the mechanisms through which scaffolds, like the graphic organizer, support students to successfully carry out text-based inquiry for purposes of constructing explanatory models in the domain of biological sciences.
The design of the graphic organizer prompted participants to engage in more elaborative processing of relevant information. The graphic organizer appeared to help participants consciously attend to whether or not the information they read was relevant to the model, a form of metacognitive awareness. The prompt in the organizer to consider how and why the information they selected was relevant to the model may have contributed to the occurrence of elaborations. This prompt may have also contributed to the nature of the elaborations that occurred, although detailed content analyses were not presented here. Content analyses of the elaborations constitute a next step for this research and subsequent investigations. These design elements may be valuable with respect to informing the design of scaffolds that seek to successfully engage students in text-based explanatory modeling.

The presence of the graphic organizer had a very limited, if any, effect on cross-text synthesis, and the frequency of cross-text synthesis was very low in both conditions. The graphic organizer only provided limited support for cross text-synthesis in that participants could “see” all the information on a single sheet and were asked to identify connections between the information they recorded. Furthermore, the structure of the texts did not require much cross-text synthesis to get the elements and links in the model, as all the elements and all but one of the links were explicitly mentioned in at least one text. Instead, the more that students elaborated on the relevant information, both within and across texts, the more likely they were to build rich understandings of how and why this information is relevant and how it fits together to construct the complete model. A text set that is intentionally designed to require cross-text synthesis to get particular elements and links in the model is needed to facilitate a more nuanced, in-depth examination of the effects of the graphic organizer on cross-text synthesis. Additional work is also needed to understand exactly what parts of the text students are connecting within and
across texts when they do engage in synthesis. A content analysis of the elaborations, as mentioned earlier would be a next step to explore this. That analysis would also be informative with respect to the prevalence of self-explanations in the think alouds, a type of elaboration often associated with higher performance on comprehension and learning measures (e.g., Aleven & Koedinger, 2002; Chi, 2000; Goldman et al., 2012).

It is interesting to note that number of links did not perform in the same ways as the other model construction measure, number of elements. In general, participants included very few links in their models. In fact, they included only zero to four out of a possible 12 links. Additionally, there was little variation with respect to which links were included. Indeed, participants who included any links mostly included the same links. Of the four participants who included four links, 100% included the link that followed sodium and water intake/loss, 100% included imbalance, 100% included vasopressin, 50% included blood sodium concentration, 50% included sense imbalance, 50% included respond to imbalance, and 50% included restored balance. Thus, although number of links trended in the same ways as number of elements, there were too few links and too limited variation to produce significant results.

Participants’ use of links may have been limited by a lack of experience with causal science models or, alternatively, their understanding of the causal relationships in the model may not have been captured by the coding system. Participants received only limited instruction about the nature of science models and had not done previous work with causal models in their science class. Thus, students may not have fully understand that, in science, models provide causal explanations of phenomena and causal links are a critical component of these models. Additionally, the coding of the causal links in students’ models was conservative and may not have fully captured students’ understanding of the causal relationships in the model. A model
part was only coded as a link if the model included explicit visual or verbal evidence of the link (e.g., an arrow, causal language). Other links were implied by the structure of the model (e.g., the ordering of elements) or reflected in the students’ talk about their model. A qualitative measure of causal links that integrates all of these sources of information may more accurately reflect the extent to which students produced causally integrated models or understood, but did not represent, the causal relationships in the model. Indeed, students’ responses during the learning application task indicated that they understood aspects of the causal relationships that were not reflected in their models. Thus, they may have understood causal relationships present in the model, but may not have understood the importance of including them in their models, may have struggled to represent these causal factors in their models, or may have represented them in ways that were not captured by the coding system. Additional instruction that emphasizes the causal nature of science models and a more holistic, qualitative coding system are needed to better support and capture students’ understanding of the causal relationships in the model.

This work indicates that scaffolds that encourage productive forms of processing can support adolescent science learners to successfully engage in text-based explanatory modeling, a task that is central to the authentic practices of scientists and a critical component of scientific literacy both within and beyond the classroom (e.g., Bazerman, 1985; Goldman et al., 2016). Indeed, our findings suggest that engaging with scaffolds that encourage productive forms of processing can impact students’ reading goals (Rouet & Britt, 2011). For example, the task instructions and scaffolds in the graphic organizer condition likely impacted students’ reading goals and, as a result, led students to select relevant information from the texts and elaboratively process this information. Through repeated engagement with this type of scaffold, students may eventually make use of these expert-like reading goals without the presence of the scaffold and
may begin to use these critical reading strategies to make sense of texts they encounter in everyday life.

This study provided important new information regarding the types of processing that underlie successful text-based explanatory modeling and examined a scaffold, the graphic organizer, that effectively supported elaborative processing of relevant information. The students who used the graphic organizer in this study successfully engaged in these productive forms of processing and may have begun to develop awareness and understanding of the crucial role they play in successfully constructing understanding from complex science texts. Following this experience, these students may have begun to approach reading more like scientists—critically evaluating what they read, deeply processing information to make sense of it, and synthesizing information within and across texts to construct understanding (e.g., Bazerman, 1985). These critical habits of mind may have enabled them to make sense of a particularly challenging text they read in biology class or understand a news article about climate change they encountered on the internet. Additional work is needed to develop and investigate instructional approaches and scaffolds that productively engage students in the authentic scientific practice of text-based explanatory modeling and effectively support them to develop the critical science literacy skills that lead to successful understanding.
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APPENDICES
Appendix A
Text Set and Relevance Content Analysis

When Too Much Water Hurts a Runner

Sports bottles of water have become indispensable accessories in gym bags and symbols of good health. In athletes and non-athletes alike, proper hydration is important because all of the systems in the body rely on water to function. In fact, the body uses water in all its cells, organs, and tissues to help transport nutrients and regulate body temperature, among other important jobs. But sports doctors are warning people not to drink too much water during endurance events like the New York City Marathon, which takes place on Sunday. Though athletes need to drink regularly during a race to prevent dehydration, experts say that excess water can lead to hyponatremia, a potentially fatal condition that is rare but increasing among recreational athletes.

Hyponatremia is an abnormally low concentration of sodium in the blood. The cause is unknown, but overconsumption of water is thought to increase the risk by diluting blood sodium.

Until recently, hyponatremia was seen almost exclusively in ultramarathons and other extremely high-endurance events, said Dr. Michael Sawkka, chief of thermal and mountain medicine at the United States Army Research Institute of Environmental Medicine in Natick, Mass. "Now we're seeing it in marathons, hiking and military occupations," he said. Symptoms include nausea and vomiting, muscle weakness, headache and disorientation, as well as bloating and puffiness in the face and fingers. In the last year or so, a dozen marathon runners in this country were known or suspected of having hyponatremia, said Dr. William Roberts, a spokesman for the American College of Sports Medicine, the professional organization of sports physicians. One victim was a 43-year-old woman who died after running the Chicago Marathon last fall.

Doctors are looking for hyponatremia more now than ever before, but they say that increased vigilance does not fully explain the increased diagnoses. Another reason may be that many recreational athletes are drinking too much water. This is dangerous because at a certain point your body can't restore the balance of water and sodium.

"We've done a good job of educating people on proper rehydration, but some people have taken that to the nth degree, thinking that the more you drink, the better," Dr. Sawkka said. Doctors say that most of the marathon runners with hyponatremia were relatively inexperienced athletes who entered races to raise money for charity.

Sodium and Water: What’s going on inside the body?

Graph of changes in a healthy individual’s blood sodium concentration over 10 hours. Sample intake of sodium and water over this period is included to demonstrate the impact of sodium and water on blood sodium concentration.

Homeostasis

Have you ever wondered why you don’t faint every time you stand up? Does it surprise you that even if you skip lunch you still can walk and talk? Explanations of those occurrences are quite complex. For instance, the cells in your brain all are exceedingly sensitive to tiny changes in the levels of oxygen and sugar. Even small decreases in those critical substances can cause fainting. Your blood pressure automatically rises when you stand up in order to maintain adequate oxygen flow to your brain. Likewise, you can skip lunch because a declining level of sugar in your bloodstream triggers your liver to release sugar held in storage. Your body must continuously make adjustments to create and maintain an environment for your brain to function.

Figure E5.1 Homeostasis. The human body is maintained in a state in which the internal conditions are balanced. When the balance is disturbed, the body adjusts its internal conditions to restore balance.

These adjustments are made automatically and assure that conditions within your body remain within rather narrowly defined limits, a condition of balance called homeostasis [see Figure E5.1). Homeostasis is a fundamental characteristic of all living systems. In fact, all organisms depend on maintaining homeostasis. Maintaining balance means life, and losing homeostatic balance for an extended period of time means death. To maintain homeostasis, two things are required. First, an organism must be able to sense when changes have occurred in the external and internal environment. Second, it must be able to respond with appropriate adjustments. For example, humans can monitor stimuli, or external signals such as cold, because we have sensory neurons in our skin that allow us to feel the outside temperature. Once the message “cold” is received in the brain, our body can respond by changing blood flow. Our heart rate may increase, and certain blood vessels may constrict. This change is involuntary, or automatic. We do not consciously control this physiological process. In other words, we do not decide what the body should do.

The human body’s response to change is quite specific as well as involuntary. For example, the body responds to cold temperature by diverting circulation to keep the most important internal organs warm. This type of response is appropriate for the external conditions. If the body becomes too hot, however, the circulatory system diverts blood flow away from the internal organs to protect them from damage caused by excess heat. These examples are rather dramatic, but the human body routinely senses and responds to thousands of small changes each day. It is through many small, specific, automatic changes that living organisms sense and react to an environment that is ever changing and sometimes hostile. Luckily, the mechanisms for maintaining balance are always on the job.

Salt: A World History
Mark Kurlansky

Without sodium, which the body cannot manufacture, the body would be unable to transport nutrients or oxygen, transmit nerve impulses, or move muscles including the heart. An adult human being contains about 250 grams of salt, which would fill three or four salt shakers, but is constantly losing it through bodily functions. It is essential to replace this lost salt. Modern scientists argue about how much salt an adult needs to be healthy. Estimates range from two-thirds of a pound to more than sixteen pounds each year. People who live in hot weather, especially if they do physical labor, need more salt because they must replace the salt that is lost in sweating. This is why West Indian slaves were fed salted food. But if they do not sweat excessively, people who eat red meat appear to derive from it all the salt they need. The Masai, nomadic cattle herders in East Africa, meet their salt needs by bleeding livestock and drinking the blood. But vegetable diets, rich in potassium, offer little sodium chloride.

Wherever records exist of humans in different stages of development, as in seventeenth- and eighteenth-century North America, it is generally found that hunter tribes neither made nor traded for salt but agricultural tribes did. On every continent, once human beings began cultivating crops, they began looking for salt to add to their diet. How they learned of this need is a mystery. A victim of starvation experiences hunger, and so the need for food is apparent. Salt deficiency causes headaches and weakness, then light-headedness, then nausea. [If deprived long enough, the victim will die] Most people choose to eat far more salt than they need, and perhaps this urge - the simple fact that we like the taste of salt - is a natural defense.

The other development that created a need for salt was the move to raise animals for meat rather than kill wild ones. Animals also need salt. Wild carnivores, like humans, can meet their salt needs by eating meat. Wild herbivores forage for it, and one of the earliest ways humans searched for salt was to follow animal trails. Eventually they all lead to a salt lick or a brine spring or some other source of salt. But domesticated animals need to be fed salt. A horse can require five times the salt intake of a human, and a cow needs as much as ten times the amount of salt a human requires.

Vaptans for the treatment of hyponatremia

Gary L. Robertson, M.D., Professor Emeritus in Medicine-Endocrinology at Northwestern University Feinberg School of Medicine

Vaptans constitute a new class of pharmaceuticals developed for the treatment of some forms of hyponatremia. Vaptans are vasopressin antagonists that interfere with the hormone vasopressin by competitively binding to its receptors in the kidney. Vasopressin performs two primary roles in the body: 1) retain water in the body and 2) constrict blood vessels. One of the most important roles of vasopressin is to regulate the body’s retention of water.

When the sodium concentration in the blood rises and the body senses that it is dehydrated, vasopressin is released. This causes the body to retain more water and produce less urine. When the sodium concentration in the blood drops, Vaptans can be administered to block the kidney’s uptake of vasopressin. This blockade causes the body to retain less water and produce more urine. This reduces body water content and raises sodium levels in the blood.

Vaptans are particularly useful to treat acute, symptomatic forms of hyponatremia, as the only other treatments currently available, such as fluid restriction and diuretics, are slow-acting and minimally effective. The use of Vaptans to treat hyponatremia is still debatable because their effects on sodium concentrations in the blood vary unpredictably from patient to patient.

Appendix B
Graphic Organizer

**Puzzling Through The Texts**

**Instructions:** As you read, use the charts below to help you keep track of the important information in each text. You don't need to fill in every box for every text. If you think that two of the pieces of information might connect with one another, draw a line between them.

Try to find at least five connections to complete your chart.

<table>
<thead>
<tr>
<th>Text 1:</th>
<th>Text 2:</th>
<th>Text 3:</th>
<th>Text 4:</th>
<th>Text 5:</th>
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<tbody>
<tr>
<td>What do I notice in this text?</td>
<td>How do I think this helps me understand and explain what is causing the problem?</td>
<td>What do I notice in this text?</td>
<td>How do I think this helps me understand and explain what is causing the problem?</td>
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Appendix C
Modeling Task Instructions

Text-Based Modeling Task

How does the body work to maintain the balance of sodium and water and what happens when this balance is disrupted?

Task Instructions

In this task, you are going to create a model to help you understand and explain a problem in science. To do this, you will first carefully read a few more texts. Next, you will use information from the texts to create a detailed model that explains how the body works to maintain the balance of sodium and water and what happens when this balance is disrupted. This task is kind of like a jigsaw puzzle - each text you read has some of the important pieces but it's up to you to figure out what they are and how they connect with one another. As you create your model, you may refer back to any of the materials you have worked with. You can use drawings, graphs, equations, words, or anything else you can think of to communicate your model. You can start working on your model at any time.

What's a model?

When you hear the word “model” you might think of fashion models. Or maybe you think of model airplanes or model cars. Scientists use the word model in a special way. In science, a model is a way to represent and explain something. Models are useful in science because they can help you explain things that are difficult to understand or difficult to observe. They can also be used to help explain what causes certain things to happen. For instance, you can use a model to explain how the heart pumps blood through your body. Scientists create models to help them understand and explain the phenomena that they study. They use drawings, graphs, equations, or words to communicate their models to others.

Adapted from materials developed by the IQWST (Investigating and Questioning our World through Science and Technology) Project.
Appendix D
Think Aloud Protocol

We’re going to start by reading a text about a big problem that some marathon runners are having that really needs to be explained. Take a few minutes to read this text and then we can talk about what we’re going to do next to figure out what is causing this problem.

[Researcher provides Text 1]

What we’re going to do today is try to unravel this problem and figure out what is causing it to happen. So you are going to read a few more texts that other kids have found really helpful in understanding what is causing this problem and use information from these texts to create a model that explains how the body works to maintain the balance of sodium and water and what happens when this balance is disrupted.

Let’s start by looking at some instructions that will help you understand the task a little bit better. Go ahead and read through these.

[Researcher provides modeling task instructions]

Ok so I’m really interested in learning more about what students like you do when you use information from science texts to create models that explain what is happening. So while you do that, I want you to describe to me what you are thinking and doing and why. For example, you can tell me about what information you might want to add to your model, what you are thinking about the information that you read, and how you are putting the information together to make your model. It will help me understand your process better if you give me as much information as you can.

To give you a better sense of what you will be doing, I’m going to demonstrate thinking aloud as I make a model using a different text.

[Researcher demonstrates modeling task]

If graphic organizer present condition: This is a worksheet that I’m going to ask you to fill out while you read the texts and make your model. Go ahead and read the instructions.

Here are the rest of the texts you’re going to read and here is the pen and paper that you will use to make your model. So this is a smart pen and its going to capture a recording of what you do-let me turn it on.

[Researcher provides texts, pen and paper, and starts LiveScribe pen recording]

Please read the texts out loud and don’t forget to describe what you are thinking and doing and why. If you don’t talk for a little while I will remind you. You will have the rest of the time today to read the texts, fill out your graphic organizer (only read if applicable), and make your model. I’ll let you know when you have 15 minutes left.
Researcher alternates the following prompts after 1 minute of silence:

- Don’t forget to describe what you are thinking and doing and why.
- Can you talk to me about what you are thinking and doing and why?
- What are you thinking and doing and why?
Appendix E
Retrospective Interview Protocol

Do you remember the texts and model you were working on yesterday? We’re going to talk about those a little more- why don’t you take a couple minutes to look back at them and refresh your memory.

We’re going to look back at the recording we took while you were making your model. I am going to ask you some questions about the model that you made. I’ll be asking the same questions about each part. One of the things I’m going to ask you is where you found the information that you added to your model. This could be one or more places in the texts, other things you have read or seen, or other things you have learned in class or in life. You can tell me about all the different places that you think the information came from, but please be as specific as possible.

Let’s look at the first part of your model.

[Researcher begins playback of model recording and pauses after each model part]

[Researcher asks the following questions after each model part]:
- Can you tell me about what this part of your model shows?
- Where did you find the information that you used in this part?
  If needed:
  - Can you show me exactly where in the texts?
  - Anywhere else?
- What did this part add to your model?
Appendix F
Learning Application Task Instructions

So the last thing we’re going to do is talk a little bit about what you learned while doing this task.

Remember the runners from the first text you read? We’re going to talk a little bit more about what’s going on inside the runners’ bodies. So let’s say that one of the runners went for a 10-mile run on a very hot day. Let’s say it was 95 degrees outside during the run and they forgot to bring a water bottle. Given the texts you read and the model you made, what do you think the runner’s physical condition would be like at the end of the run and why? What would the runner’s body need to do to restore balance and why?
Appendix G
Model Demonstration Materials

The heart is a muscular organ that pumps blood through the body. The heart consists of cardiac muscles, nervous tissue, and connective tissues. The septum divides the heart lengthwise into two sides. The right side pumps blood to the lungs, and the left side pumps blood to the other parts of the body.

James, Katherine M
So it sounds like the heart is important. I'm going to add that to my model [DRAW heart]

James, Katherine M
So I think that this is telling me that the heart is divided into different sections. It sounds like there is a division from top to bottom—let me try to show that in my model [DRAW septum]

James, Katherine M
It says the right side pumps blood to the lungs [DRAW arrow, WRITE lungs] and the left side pumps blood to the other parts of the body [DRAW arrow, WRITE body]

James, Katherine M
Oh so it looks like this diagram connects with the sections they described in the text earlier. I see the septum here and it looks like there is another division across the heart. I'll add that one to my model [DRAW division]

James, Katherine M
Oh so this relates to the diagram. So the lower chambers are ventricles [WRITE ventricle] and the upper chambers are atria [WRITE atrium]

James, Katherine M
I think this is telling me more about how the blood moves in the different sections. So it sounds like the blood moves from the top to bottom like this [DRAW down arrow]
## Appendix H

**Model Codebook**

<table>
<thead>
<tr>
<th>Model Elements</th>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Homeostasis/ Balance</strong>&lt;br&gt;(Initial)</td>
<td>Element represents homeostasis or a condition of balance within the body. This code encompasses the initial condition of balance and those that cannot be otherwise identified but does not include restored balance/homeostasis.</td>
<td>Balance, Homeostasis, Maintain sodium and water, Control, Balance scale, Water and salt, Just the right amount of salt and water</td>
</tr>
<tr>
<td><strong>Sodium/Water Consumed/Lost</strong></td>
<td>Element represents the intake or loss of sodium and/or water. Does not include urine.</td>
<td>Drink Water, Eat salt, Meat, Water bottle, 250 gram of salt, Sweat, Lose salt while running</td>
</tr>
<tr>
<td><strong>Change in Blood Sodium Concentration</strong>&lt;br&gt;(Initial)</td>
<td>Element represents a change in the concentration of sodium in the blood that leads to an imbalanced state and those that cannot be otherwise identified.</td>
<td>Sodium Concentration in Blood, BSC</td>
</tr>
<tr>
<td><strong>Imbalance/No Homeostasis</strong></td>
<td>Element represents a condition of imbalance or a lack of homeostasis.</td>
<td>No homeostasis, Imbalance, Homeostasis Lost, Unbalanced scale, Too much salt, No water, Hyponatremia, Dehydration</td>
</tr>
<tr>
<td><strong>Body Senses Imbalance</strong></td>
<td>Element represents the body (e.g., brain) sensing the imbalanced state. (Body to brain)</td>
<td>Body senses something is wrong, Brain gets signal from body, Brain tells us we don't have enough water, Arrows to brain</td>
</tr>
<tr>
<td><strong>Body Responds to Imbalance</strong></td>
<td>Element represents the body’s (e.g., brain) general response to correct imbalance (Brain to body)</td>
<td>Body tries to keep more water, Body adjusts to maintain balance, Brain sends message to body, &lt;Arrows to body&gt;, Body makes changes</td>
</tr>
<tr>
<td><strong>Vasopressin Released/ Vaptans Administered</strong></td>
<td>Element represents the release of vaptans or administration of vasopressin. Does not include general response to restore balance.</td>
<td>Vaptans are administered, Body sends vasopressin, Kidneys release vasopressin, Vaptans block the kidneys, Kidneys respond</td>
</tr>
<tr>
<td><strong>Body Retains More/Less Water</strong></td>
<td>Element represents the body retaining more or less water.</td>
<td>Body holds the water that it has, Body blocks water from being released</td>
</tr>
<tr>
<td><strong>Body Produces More/Less Urine</strong></td>
<td>Element represents the body producing more or less urine</td>
<td>Body makes more urine, Water released in pee, Urine</td>
</tr>
<tr>
<td><strong>Change in Blood Sodium Concentration</strong>&lt;br&gt;(Restore)</td>
<td>Element represents a change in the concentration of sodium in the blood that restores balance but does not include an initial change in BSC.</td>
<td>Sodium in blood goes back up, Restores the blood sodium concentration</td>
</tr>
<tr>
<td><strong>Homeostasis/ Balance</strong>&lt;br&gt;(Restored)</td>
<td>Element represents homeostasis or balance within the body. This code includes only restored balance/homeostasis, not an initial state.</td>
<td>Returns the body to homeostasis, This makes the body balanced again</td>
</tr>
<tr>
<td><strong>Balance Not Restored/ Imbalance Sustained</strong></td>
<td>Element represents the body's inability to restore balance or sustained imbalance.</td>
<td>Body can't correct the imbalance, Imbalance is sustained, Can't restore homeostasis</td>
</tr>
<tr>
<td><strong>Symptoms Experienced</strong></td>
<td>Element represents symptoms that are experienced.</td>
<td>Body doesn’t feel right, Runner feels sick, Vomiting, Nausea, Bloating, Sick figure</td>
</tr>
<tr>
<td><strong>Death</strong></td>
<td>Element represents death that can occur.</td>
<td>Eventually you die, Dead figure, Can even cause death</td>
</tr>
<tr>
<td><strong>Link</strong></td>
<td>Explicitly indicates a relationship between elements, including temporal and causal relationships. Links are identified relative to the element that they follow.</td>
<td>Causes, And, &lt;Arrow&gt;, Which, Results in, Because, &lt;Connecting Line&gt;, Then…</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td>Elements were coded as inaccurate if they reflected information that is not scientifically normative.</td>
<td>Salt gets released from liver, Sugar or oxygen instead of salt, Blood pressure or blood flow (instead of blood sodium concentration), Too much change hurts the body, Liver instead of kidneys</td>
</tr>
</tbody>
</table>
Appendix I
Example Model Coding

Examples of one lower and one higher scoring model are included below to illustrate the application of the model coding scheme. The scores that resulted from this coding are included above the models. On the images below, colored boxes and text indicate coding marks. All other marks are part of the participants’ models.

Lower Scoring Model (2 elements, 0 links)
Higher Scoring Model (9 elements, 1 link)

It all works because the body can sense when you need certain or have too many of one nutrient. However when you do not give your body the time or it disrupts the body balance in your body because it has too much of one nutrient and this affects your body and can lead to death.
Appendix J
Example Learning Application Task Coding

Examples of one lower and one higher scoring learning application task are included below to illustrate the application of the model coding scheme to the transcripts. The scores that resulted from this coding are included above the transcript excerpts. On the images below, colored boxes and text indicate coding marks.

Lower scoring learning application task (Condition Score: 1, Cause Score: 2, Restore Score: 2, Overall learning application task score: 5)

Higher scoring learning application task (Condition Score: 3, Cause Score: 3, Restore Score: 4, Overall learning application task score: 10)
### Appendix K
Think aloud transcript excerpt with utterances indexed to text sections, relevance coding

<table>
<thead>
<tr>
<th>Utterance</th>
<th>Referenced Text Section</th>
<th>Text #</th>
<th>Sent. #</th>
<th>Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>So it's like a graph and it shows the concentration of sodium in the person's blood throughout them intaking water.</td>
<td>Graph</td>
<td>2</td>
<td>1</td>
<td>Relevant</td>
</tr>
<tr>
<td>So if they don't intake water for a while as soon as they drink the water and then their sodium level will go way down.</td>
<td>Same as above</td>
<td>2</td>
<td>1</td>
<td>Relevant</td>
</tr>
<tr>
<td>Then once they take sodium again it will resurface and then go up.</td>
<td>Same as above</td>
<td>2</td>
<td>1</td>
<td>Relevant</td>
</tr>
<tr>
<td>The sodium level is kind of going up and down based on whether they take sodium or water.</td>
<td>Same as above</td>
<td>2</td>
<td>1</td>
<td>Relevant</td>
</tr>
<tr>
<td>So it said that your brain is gonna make sure that those sodium level is all balanced out.</td>
<td>Your body must continuously make adjustments to create and maintain an environment for your brain to function.</td>
<td>3</td>
<td>8</td>
<td>Relevant</td>
</tr>
<tr>
<td>So that kind of tells me that if anything is too high or too low it levels them...like balances back out.</td>
<td>Diagram</td>
<td>3</td>
<td>9</td>
<td>Relevant</td>
</tr>
<tr>
<td>So it's kind of subconscious in our body and our brain just does it by itself.</td>
<td>This change is involuntary, or automatic. We do not consciously control this physiological process. In other words, we do not decide what the body should do.</td>
<td>3</td>
<td>20-22</td>
<td>Non-relevant</td>
</tr>
<tr>
<td>So it'll never stop until we die and as long as we're alive our body will keep adapting to the environment and making sure our body is doing good.</td>
<td>It is through many small, specific, automatic changes that living organisms sense and react to an environment that is ever changing and sometimes hostile. Luckily, the mechanisms for maintaining balance are always on the job.</td>
<td>3</td>
<td>28-29</td>
<td>Non-relevant</td>
</tr>
<tr>
<td>We can't make it on our own.</td>
<td>Without sodium, which the body cannot manufacture, the body would be unable to transport nutrients or oxygen, transmit nerve impulses, or move muscles including the heart</td>
<td>4</td>
<td>1</td>
<td>Non-relevant</td>
</tr>
<tr>
<td>We have to find a way to consume it.</td>
<td>Same as above</td>
<td>4</td>
<td>1</td>
<td>Non-relevant</td>
</tr>
<tr>
<td>Also our sodium levels are somewhat responsible for the moving of our muscles and that includes the heart so without the correct sodium levels our heart would stop.</td>
<td>Same as above</td>
<td>4</td>
<td>1</td>
<td>Non-relevant</td>
</tr>
<tr>
<td>Since we can't manufacture it.</td>
<td>Same as above</td>
<td>4</td>
<td>1</td>
<td>Non-relevant</td>
</tr>
<tr>
<td>So we crave salt to make sure we don't go without it.</td>
<td>Most people choose to eat far more salt than they need, and perhaps this urge - the simple fact that we like the taste of salt- is a natural defense.</td>
<td>4</td>
<td>17</td>
<td>Non-relevant</td>
</tr>
<tr>
<td>S: So even animals have found ways to make sure that their sodium levels are ideal or in the right place and they've done this by over time they evolved and sought out resources for that like the springs.</td>
<td>Animals also need salt. Wild carnivores, like humans, can meet their salt needs by eating meat. Wild herbivores forage for it, and one of the earliest ways humans searched for salt was to follow animal trails. Eventually they all lead to a salt lick or a brine spring or some other source of salt.</td>
<td>4</td>
<td>19-22</td>
<td>Non-relevant</td>
</tr>
<tr>
<td>It's a treatment?</td>
<td>Vaptans constitute a new class of pharmaceuticals developed for the treatment of some forms of hyponatremia.</td>
<td>5</td>
<td>1</td>
<td>Relevant</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>-----</td>
<td>----</td>
<td>---------</td>
</tr>
<tr>
<td>I think it's like a treatment...the Vaptans.</td>
<td>Same as above</td>
<td>5</td>
<td>1</td>
<td>Relevant</td>
</tr>
<tr>
<td>And then they...it's called a vasopressin antagonist</td>
<td>Vaptans are <em>vasopressin antagonists</em> that interfere with the hormone vasopressin by competitively binding to its receptors in the kidney.</td>
<td>5</td>
<td>2</td>
<td>Relevant</td>
</tr>
<tr>
<td>They somehow help out with making sure water levels are good.</td>
<td>Vasopressin performs two primary roles in the body: 1) retain water in the body and 2) constrict blood vessels. One of the most important roles of vasopressin is to regulate the body’s retention of water.</td>
<td>5</td>
<td>3-4</td>
<td>Relevant</td>
</tr>
<tr>
<td>So when Vaptans are released they block the kidney from using up water and then…</td>
<td>When the sodium concentration in the blood drops, Vaptans can be administered to block the kidney’s uptake of vasopressin. This blockade causes the body to retain less water and produce more urine.</td>
<td>5</td>
<td>7-8</td>
<td>Relevant</td>
</tr>
<tr>
<td>Wait no…that's wrong.</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Non-relevant</td>
</tr>
<tr>
<td>It reduces water and that makes the sodium levels go up.</td>
<td>This reduces body water content and raises sodium levels in the blood.</td>
<td>5</td>
<td>9</td>
<td>Relevant</td>
</tr>
<tr>
<td>So Vaptans have been used for a while now to treat hyponatremia.</td>
<td>Vaptans are particularly useful to treat acute, symptomatic forms of hyponatremia, as the only other treatments currently available, such as fluid restriction and diuretics, are slow-acting and minimally effective.</td>
<td>5</td>
<td>10</td>
<td>Relevant</td>
</tr>
<tr>
<td>There's only like two other or not many other treatments for it and they're a lot less effective than the Vaptans</td>
<td>Same as above</td>
<td>5</td>
<td>10</td>
<td>Non-relevant</td>
</tr>
</tbody>
</table>
## Appendix L
Types of Processing and Relevance Codebook

<table>
<thead>
<tr>
<th>Types of Processing</th>
<th>Definition</th>
<th>Example think aloud utterances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restatement</td>
<td>Comment repeats a part of the text verbatim. Restatements can include removing/deleting words but not adding new words (except a, the, etc.)</td>
<td>&quot;Your body must continously make adjustments&quot;; &quot;The circulatory system diverts blood flow away from the internal organs&quot;</td>
</tr>
<tr>
<td>Paraphrase/Summary</td>
<td>Paraphrase/summary is repeating the gist of a sentence in the text without adding additional information. Paraphrases can be include both verbatim words or like words (synonyms). It can include transformations, but can not include any ideas that were not in the text.</td>
<td>&quot;So like it depends from patient to patient how the sodium concentration affects you so it can affect you in different ways than others.&quot;; &quot;Like in East Africa they have to drink the blood of livestock to get the salt and in west india they have to eat salted food.&quot;; &quot;The more sweat...the more salt you use you need more salt.&quot;</td>
</tr>
<tr>
<td>Elaboration</td>
<td>Comment creates new knowledge that serves the purpose of improving understanding of the text information. Must add information that goes beyond what is in the text. Can involve meaningful integration of text content with prior knowledge or generation of a connection between the text and information that was not explicitly stated in the text.</td>
<td>&quot;There's functions in your body that help retain water in the body so there has to be one that contains or retains sodium in the body&quot;; &quot;Ok the picture...basically the picture is showing how if like something goes away then it evens itself back out, adding an extra piece so that everything is normal in your body like it should be.&quot;</td>
</tr>
<tr>
<td>Elaboration: Cross-Text Synthesis</td>
<td>Comment creates new knowledge by synthesizing information from multiple texts. Must explicitly reference info from multiple texts.</td>
<td>&quot;So I put that runners could have too much of this or too little of this in their system when they're running so that could be one reason why they get sick while running.&quot;; &quot;The symptoms for lack of salt reminds me of umm...homeostasis because like you get a headache and you start feeling nausea and everything, which is the same thing that salt has.&quot;</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Comment conveys a judgment about some aspect of the text or comment OR comment conveys a positive or negative judgment about some aspect of the reader</td>
<td>&quot;That's nasty&quot;; &quot;It was basically straight forward.&quot;; &quot;The balance beam is important kind of.&quot;; &quot;I don't really get this&quot;; &quot;I was wondering about that myself.&quot;</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Comment is coded as inaccurate if it includes information that is scientifically non-normative given the &quot;expert&quot; explanatory model that participants are being asked to construct.</td>
<td>&quot;So it's saying that not everyone vaptans are the same so they probably don't produce enough vasopressin to balance out the body's balance of sodium and water.&quot;</td>
</tr>
<tr>
<td>Relevance</td>
<td>Relevant Comment pertains to a section of the text that contains only relevant information.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not Relevant Comment pertains to a section of the text that contains only irrelevant information, a mix of relevant and irrelevant information, or could not be clearly linked to a section of the text.</td>
<td></td>
</tr>
</tbody>
</table>
VITA

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- Participated in the design and analysis of curricular modules and assessments designed to support evidence-based argumentation and disciplinary literacy in middle and high school science classrooms
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- Conducted qualitative and quantitative analysis of science and Engineering concept inventories for purposes of developing a validity framework and instructional applications
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- Designed, executed, and analyzed quantitative research on language and analogy in learning
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Director of Curriculum and Research
-Designed SAT-aligned curriculum in evidence-based reading and writing
-Researched learning outcomes based on instructional approaches and educational technology

Clinical Research Analyst
-Partnered with and traveled to hospitals and academic medical centers to increase research compliance
-Analyzed over 200 clinical research protocols in oncology for compliance with federal regulations
-Authorized policies, procedures, and tools to create and facilitate a research management office
-Interviewed major stakeholders and synthesized divergent perspectives into a cohesive action plan

Research Assistant
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