Effects of Pre-reading Instructions on the Comprehension of Science Texts

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ABSTRACT

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This study examined how three different pre-reading (or relevance) instructions led to different learning outcomes for middle school students reading science texts on the topic of sweetness. The first was a generic instruction to read for understanding. The second prompted students to form a holistic explanation of the topic of sweetness, and the third instruction prompted students to focus on the core scientific principle of the relationship between structure and function. The latter two were specifically designed to align with science disciplinary goals. A comparison of the three treatments found that the generic instruction and the structure-function instruction led to better learning outcomes, measured by recall, short-answer performance questions, and a traditional multiple-choice/short-answer assessment. A qualitative analysis of the data also revealed some small yet notable differences in the recall pattern of students, such as an increased recall of key ideas for the structure-function instruction. This effect was seen predominantly for higher-skilled readers. The results suggest the possibility that relevance instructions targeting core ideas may help to orient students to the key ideas and explanations in scientific text, especially for higher-skilled readers, and indirectly highlights some of the challenges for students with less reading competencies. Overall, this study provides greater insight into how middle-school students read science texts, the effectiveness of instructor-provided relevance instructions in promoting (higher-level) comprehension of science texts, and implications for teachers on how to use texts in science instruction.

Keywords: relevance instructions, pre-reading instructions, comprehension, science texts, middle school students, low- versus high-skilled readers.

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To future teachers and researchers
in science education

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Chapter 1

INTRODUCTION

"Engaging students with standard scientific explanations of the world—helping them to gain an understanding of the major ideas that science has developed—is a central aspect of science education." (National Research Council, 2012, p. 68).

Teachers routinely assign reading from science texts as part of instruction (Banilower, Smith, Weiss, Malzahn, Campbell, & Weis, 2013; Digisi & Willett, 1995). The Report of the 2012 National Survey of Math and Science Teachers showed that teachers assign students to read science materials (e.g. from a textbook or module) at least once a week (48% of elementary school teachers, 56% of middle school, and 37% of high school teachers); and when asked what they did in their most recent lesson, 53% of elementary school, 50% of middle school, and 35% of high school science teachers reported having their students read about science. Reform-minded science educators/researchers have criticized instructional methods that place importance on learning largely from science texts and the passive transmission of knowledge (Ball & Feiman-Nemser, 1988); however, more recently, educators have acknowledged the critical place of texts in learning about—and doing—science. Learning how to read science texts (as well as to write, reason, and communicate) in line with disciplinary practices is one of the skills that students should learn in their science classes (see Cervetti, Pearson, Bravo, & Barber, 2006; Pearson, Moje, & Greenleaf, 2010).

For teachers, one primary goal of having students read science texts is to help them build a base of content knowledge (Goldman & Bisanz, 2002). The quotation from the K-12 Framework presented above affirms the importance of engaging students with the key ideas and principles of the discipline. Learning from text can be one component of a robust learning experience—to help students achieve an accurate and coherent understanding of science concepts (Bransford, Brown, & Cocking, 2000); research, however, has highlighted some of the challenges in comprehending science texts. Among other things, students have difficulty grasping main ideas or important details (e.g., Garner, Gillingham & White, 1989), to form an accurate and coherent understanding of the principles or mechanisms described (e.g., Roth & Anderson, 1988), and to learn the information so as to be able to apply the information in different contexts (Bransford et al., 2000). The reasons for these difficulties lie in the interaction of text, reader, and task factors (Snow, 2002). For example, science texts are often conceptually dense and contain many specialized or technical terms (Fang, 2005). Moreover, thorough comprehension of science texts often requires a high level of inferencing on the part of the reader, which is challenging for those with low levels of prior knowledge (Best, Rowe, Ozuru, & McNamara, 2005).

Pre-reading Instructions

Research suggests that one way to help students to understand expository text in general is through the use of pre-reading instructions in the form of learning objectives or pre-reading questions (McCrudden, Magliano, & Schraw, 2010). These aids, provided at the outset of reading, are thought to support students' learning by orienting them to important or instructionally relevant material in the text. Research on the effectiveness of learning goals and objectives was particularly robust in the 1970s and 1980s, with various reviews written during that time (e.g., Andre, 1979; Hamilton, 1985). More recently, researchers (notably McCrudden & Schraw) have revived interest in what they term "relevance instructions." Relevance instructions are cues provided by the teacher, usually at the outset of a reading task, that signal which information in the text is relevant to the particular reading situation (McCrudden et al., 2010). These instructions can define a general reading purpose or perspective (such as, “Read in order to be able to write a summary” or “Read from the perspective of a scientist”), or they can target more specific ideas or segments of information (such as, “Explain the factors that cause erosion” or “What are two types of cells?”). In general, relevance instructions include any pre-reading instructions that are intended to enhance the reader’s attention to, and cognitive processing of, some specified aspect of the reading material.

Research on pre-reading instructions has shown that they significantly influence students’ reading behaviors or strategies, especially what students attend to when reading text, as measured by reading times, eye fixation patterns and reports from think-alouds (e.g., Braten & Samuelstuen, 2004; Cerdan, Vidal-Abarca, Martinez, Gliabert, & Gil, 2009; Kaakinen, Hyoenae, & Keenan, 2002; van den Broek, Lorch, Linderholm, & Gustafson, 2001). As for their effect on learning, studies have repeatedly shown that relevance instructions can increase memory for relevant text segments, as measured by recognition or recall questions (Hamilton, 1985; McCrudden & Schraw, 2007).

Relatively fewer studies have examined the effect of relevance instructions on higher-order, or conceptual, learning and the ability to apply the learned information. A number of recent studies have shown that relevance instructions, particularly those that draw attention to main ideas or those that prompt higher-level integrative processing, result in a higher quality of learning as measured by conceptual and essay questions (Cerdan & Vidal-Abarca, 2008; Lehman & Schraw, 2002; McCrudden, Schraw, & Hartley, 2006).

Most of this research on relevance instructions has been conducted using college students (see review by McCrudden & Schraw, 2007). Yet, research shows that younger students (i.e., primary and secondary school students) face particular challenges in reading expository text for a variety of reasons, such as their lower levels of domain knowledge (see Best, Floyd, & McNamara, 2008). More research is needed for the primary and secondary school student population in order to characterize the possible effect of relevance instructions on their learning from texts.

Pre-reading relevance instructions may improve students' conceptual learning of *science* texts in particular for two main reasons. First, such instructions would help to address the problem of the students' low prior knowledge in science. Students generally possess little topic- or domain-knowledge of the content they encounter in textbooks [see Alexander's Model of Domain Learning (Alexander, 1997b)]. Students' lack of prior knowledge and their unfamiliarity with the core concepts of the discipline make it more difficult for them to identify the important ideas when reading. For example, research has shown that "seductive details" (i.e., more vivid, but less important information) can dominate the attention of the reader and skew their learning from the text (Garner et al., 1989). Pre-reading relevance instructions designed to focus the reader's attention to the important scientific ideas of the topic would support students' recognition of significant information and overall comprehension of the text.

Second, relevance instructions that ask students to generate explanations, a higher-level form of cognitive processing, may help them to relate the important facts together to form a more coherent and integrated understanding of the topic. Literacy research has shown that developing a coherent understanding of a particular text is strongly related to the amount of causal inferencing or reasoning on the part of the reader—although most of this work has been conducted using narrative texts (e.g., O'Brien & Myers, 1987; Graesser, Singer, & Trabasso, 1994).

A relevance instruction that prompts for an explanation would additionally reflect the disciplinary goals of science. Although one major goal of science is to provide explanations of natural phenomena [National Research Council (NRC), 2012], students, in contrast, often perceive learning science as the memorization or accumulation of facts (Tsai, 2004). Furthermore, textbook learning objectives often target specific segments of information (e.g., important concepts, definitions, or mechanisms), which while necessary for understanding the topic, do not necessarily encourage students to integrate the information into a coherent whole. In contrast, relevance instructions that are aligned with the discipline would ideally encourage students to provide holistic explanations of natural phenomena, as well as more effectively orient them to the core science concepts and overarching principles contained in the text.

In this study, I investigated the effects of three different pre-reading relevance instructions on middle school students' comprehension of a science text. The first was a generic instruction that asked students to understand the text as best as they could. The second instruction prompted students to provide a holistic integrated explanation of the phenomenon described in the text. The third instruction oriented students toward core ideas in the text and encouraged higher-level processing of those ideas in order to understand an overarching scientific concept (in this case, the relationship between structure and function). The latter two instructions were specifically meant to align with disciplinary objectives.

I also sought to investigate whether these relevance instructions would have different effects for low-, average-, and high-skilled readers because so few studies have been conducted to investigate the interaction of relevance instructions and reading skill (e.g., Di Vesta & Di Cintio, 1997; Kaakinen et al., 2002; Reynolds, Trathen, Sawyer, & Shepard, 1993).

In the next chapter, I review the research related to the effect of pre-reading instructions on learning from text, which then provides a springboard to my research questions, the methodology I used, and findings from my study.

Chapter 2

LITERATURE REVIEW

In the literature review, I first discuss cognitive models of reading comprehension to provide a theoretical framework for the processes involved in comprehending science texts. Then, I review research on learning science content and the difficulties associated with learning science concepts when reading science text. Lastly, I review the literature on the effect of pre-reading instructions on learning from texts. This literature review encompasses an integrated perspective, including research from the field of literacy and reading comprehension as well as from the field of science education. It refers to historically important science learning documents (e.g., Duschl, Schweingruber, & Shouse, 2007), which addressed core content and conceptual learning, as well as to the current K-12 Framework embodied in the Next Generation Science Standards (NRC, 2012; NGSS Lead States, 2013), which intertwines the students' learning of content with authentic disciplinary practice.

Theoretical Framework: Comprehension and Learning from Expository Texts

A substantial amount of research in reading comprehension has led to the development of a number of prominent theories, such as Kintsch's Construction-Integration model (W. Kintsch, 1988; W. Kintsch, 1998; van Dijk & Kintsch, 1983); Constructionist theory (Graesser et al., 1994, see also Graesser, Millis, & Zwaan, 1997); and the Landscape model (van den Broek, Young, Tzeng, & Linderholm, 1999). (See also the comprehensive review by McNamara and Magliano (2009) for a comparison of nine major reading comprehension theories.) Though different in emphases, these theories describe comprehension as a process of constructing meaning as a reader interacts with a text. One key element is the process of making *inferences*, or connections, between text segments in order for the reader to develop a coherent mental representation of the text's content (Graesser et al., 1994). Inferences at the *local* level help a reader construct meaning at the sentence level, such as relating pronouns to their referents or connecting sentences that are not explicitly associated. In contrast, *global* inferences help the reader form the overall, or gist-level, meaning of the text. They involve determining how sentences and passages are related to one another and to the overall topic (E. Kintsch, 2005).

This inference-making process is both automatic and strategic. As a reader encounters new information, it triggers the activation of related ideas and knowledge structures from the reader's memory. Research seems to indicate that this activation is primarily the result of automatic, or passive, processes (Lassonde, Smith, & O'Brien, 2011). Both the new information as well as prior knowledge (whether accurate or not) are made available in working memory for connections to be generated in the process of forming a mental representation of the text.

Learning outcomes: Mental representations. The understanding that results from engaging with a text is often described as a *mental* or *cognitive representation* in the reading research literature (e.g., Goldman & Rakestraw, 2000). In his seminal theory of discourse processing, Kintsch described three levels of cognitive representations that are relevant to this study (W. Kintch, 1988, 1998). The *surface code* refers to verbatim words and sentences, and represents pure memory of the material without meaning. In contrast, the *textbase* reflects the beginning of true comprehension. This level of cognitive representation includes what is explicitly in the text, along with the inferences that are needed to comprehend the explicit meaning of the text. Finally, the *situation model* represents the reader's interpretation of the text. It reflects the reader's internalized understanding of the content, shaped by his or her purpose and goals for reading, and is formed as the reader integrates information in the text with prior knowledge that has been activated by the text.

The textbase representation is thought to be sufficient for recognition or recall of the text's content. However, learning at the textbase level does not necessarily enable long-term or flexible use of the knowledge. The situation model, in contrast, reflects a deeper level of learning since the content of the text has been integrated with the reader's prior knowledge schema. This type of learning would allow for more flexible use of the knowledge, which is needed for higher-level skills such as applying, analyzing, or creating information.

It is important to note that the formation of a situation model (i.e., how extensively the learner has integrated the information with his or her own knowledge base) does not necessarily reflect the overall quality of learning. For example, students can develop and retain deeply held misconceptions about a particular topic (see for example, Roth & Anderson, 1988). Thus, to evaluate the quality of learning, a learner's mental representation must be assessed along a number of dimensions: its accuracy, its organization and coherence (informational and causal completeness), as well as how extensive or elaborate it is, and how integrated is the content with the learner's own knowledge base.

Forming Meaningful Connections among Ideas to Learn Science.

In *Taking Science to School,* the editors outlined the important characteristics needed by students to attain proficiency in science (Duschl, Schweingruber, & Shouse, 2007). Among them, the first was "to know, use, and interpret scientific explanations of the natural world." The editors further elaborated that "This strand stresses *acquiring facts" and "building organized and meaningful conceptual structures that incorporate these facts* (emphasis added)*"* (p. 39). The forming of appropriate and meaningful relationships among ideas seems to be a major component in the progression of disciplinary understanding. In fact, the organization of conceptual structures is one feature that distinguishes novices from experts. Whereas the knowledge of novices tends to be fragmented or unconnected (Biggs & Collis, 1982; diSessa, 2006), experts have a knowledge base that is richly structured, and organized around core concepts and principles in such a way that guides their thinking and enables them to apply their knowledge in new situations (Chi, Feltovich, & Glaser, 1981; Chi, Glaser, & Rees, 1982).

Teachers often assign reading as a way for students to acquire facts and to engage with scientifically accepted ideas. Research, however, shows that students often fail to achieve "organized and meaningful conceptual structures" or coherent mental models when reading a piece of scientific text (e.g., Roth & Anderson, 1988). Learning can be shallow or focused on memorizing terms rather than on understanding concepts and overarching principles (e.g., Roth & Anderson, 1988). Studies have shown that students have difficulty recognizing main ideas and important details (e.g., see review by Alexander & Jetton, 1996; Garner et al., 1989), and learning the material in a deep way so as to be able to apply the knowledge in other situations (e.g., diSessa, 2006).

Challenges of Learning from Science Texts

There are a number of reasons why the comprehension of science texts can be so difficult for students. Literacy researchers typically refer to three categories of factors—those related to the text, the reader, and the activity/context of reading (Snow, 2002). I will first discuss text and reader factors that are particularly relevant to the comprehension of science texts and the challenges associated with it, and then address contextual factors—and the notion of relevance instructions—later in this review.

Characteristics of science texts. Science texts have specific linguistic features that make them difficult to understand (Bryce, 2013; Gomes & Mensah, 2016; Lee & Spratley, 2009; see also the discussion in NRC, 2012, p. 74). In particular, they are abstract, informationally dense, and contain a large proportion of specialized terms (Fang, 2005; Gee, 2009; Goldman & Rakestraw, 2000; Snow, 2010; Yager, 1983). The specialized terms often represent abstract concepts or complex relationships (e.g., atomic-molecular theory, photosynthesis), and even common words can have meanings that differ from their everyday use (e.g., host and system). In contrast with narrative stories, science texts possess certain expository text structures, such as classification, compare-and-contrast, or cause-and effect patterns (Meyer, 1975), which are less familiar to students.

Other factors, such as the text's coherence, the relevance of its content, and the concreteness and vividness of its writing style, have a substantial effect on a reader's situational interest, which in turn affects the learning of the material (Schraw, Flowerday, and Lehman, 2001). Yet, relatively recent reviews of science curriculum materials have shown that textbooks often fall short on all these qualities, (Kesidou & Roseman, 2003; McTigue & Slough, 2010; Roseman, Stern, & Koppal, 2010).

Characteristics of science learners. In addition to textual features, a number of reader-related factors play a strong role in students' comprehension of expository text. They include reading ability (Ozuru, Dempsey, & McNamara, 2009); prior knowledge (Alexander, Kulikowich, & Jetton, 1994a; Best et al., 2005); student interest (Schiefele, 1999); and beliefs (Tsai, 2004).

Reading skill. According to the simple view of reading (Gough & Tumner, 1986; Hoover & Gough, 1990; see also Hulme & Snowling, 2011), an individual's reading skill depends on his or her word recognition ability and (oral) language comprehension skill (which includes, among other factors, receptive vocabulary and grammatical knowledge). Another possible factor that affects reading comprehension (though less directly related than word recognition and listening comprehension) is a reader's working memory capacity (WMC). WMC refers to the combined ability of a reader to actively hold and process information (both incoming text and the related information activated from memory) in temporary storage (Daneman & Merikle, 1996; Just & Carpenter, 1992). In general, readers with lower WMC are less able to relate and connect information in order to create a coherent mental representation (Oakhill, 1983). Another factor to note that influences reading skill is the strategic processing of the reader—or the active, effortful processes a reader engages in (such as re-reading or use of self-explanations) to maintain coherence in their understanding of the text (Best et al., 2005; Yuill & Oakhill, 1991).

Reading skill is a major factor in comprehension (Snow, 2002), but researchers are just beginning to understand its specific role in reading science texts (Hall, Maltby, Filik, & Paterson, 2016; Ozuru et al., 2009; Tarchi, 2010). Reading skill is particularly important given the density of new information and the unfamiliar linguistic structure of science texts, which make it difficult for students to connect information into a coherent representation (Ozuru et al., 2009).

The role of prior knowledge. A learner's prior knowledge is known to play a critical role in comprehension, particularly for science text (Best et al., 2005; Cervetti & Hiebert, 2015; Kaakinen, Hyonenae & Keenan, 2003). A number of studies have described the adverse effect of low prior knowledge on learning from expository texts (e.g., see reviews by Alexander et al., 1994a; Schallert, 1982; Voss & Silfies, 1996) and specifically for science texts (Best et al., 2005, Ozgungor & Guthrie, 2004). Prior knowledge, among other things, helps a reader identify the correct meanings of words and to make the local and global inferences necessary for coherent understanding (Best et al., 2008). Learners with high prior knowledge can access background information with little imposition on WMC (Graesser et al., 1994) and fill in informational gaps in the text (Ozuru et al., 2009). They also may be able to process information more effectively because they have a better understanding of how details relate to the main ideas (Rapp, van den Broek, McMaster, Kendeou, & Espin, 2007).

The problem for students in science is that they typically know little about the topic they are assigned to read. Students may have had shallow or no exposure to academic vocabulary and fundamental concepts, such as “synthesis” or “molecule”, or scientific notions of energy and force (Fisher, Grant, & Frey, 2009; Snow, 2010). Without this background knowledge to scaffold their learning, students have difficulty making the inferences necessary to build a coherent representation of the content, and thus have difficulty identifying or recalling important relationships within a text (Best, et al., 2008; Ozgungor & Guthrie, 2004). Unfortunately, many scientific texts assume a reader’s prior knowledge and do not supply the background information needed for complete understanding (Best et al., 2005).

The role of interest and beliefs. Student interest and beliefs about learning are two other significant reader characteristics that influence comprehension (e.g., reviews by Alexander & Jetton, 1996; Schiefele, 1999; see also Chin & Brown, 2000). Students who have low prior knowledge of a topic—which is often true of science learners—typically have low intrinsic interest in reading a text on that topic. They can, however, hold varying degrees of *situational* interest (Alexander, 1997b), which can arise due to features of the text, such as the presence of novel, vivid, or personally relevant information (see Hidi & Renninger, 2006), or due to contextual factors. At times, the interesting elements of a text can detract from a reader’s understanding of its important ideas. A number of studies have shown how *seductive details*—additions to text that are highly interesting but unimportant to understanding the topic—decrease the learning of important ideas (e.g., Garner et al., 1989; Harp & Mayer, 1998; Lehman, Schraw, McCrudden, Hartley, 2007; Wade, Schraw, Buxton, & Hayes, 1993). This effect appears to be even stronger for younger readers (Garner et al., 1989).

Lastly, student beliefs about what constitutes learning can also have an impact on what students learn from the text. Students with a *surface* approach to learning often learn for external reasons—e.g. to satisfy the demands of the task and to achieve the "signs" of learning; whereas, students with a *deep* approach aim for coherence and meaningful understanding (Marton 1976c, 1983; cf. Ramsden, 1988). These learning orientations are likely related to a student's motivational orientation (intrinsic or extrinsic) as well as student beliefs about what constitutes learning (memorizing information or preparing for tests versus understanding information—see for example, Marton, Hounsell, & Entwistle, 1994 and Tsai, 2004). Overall, it is not uncommon for students to view learning as being able to answer questions posed by the teacher or textbook or to pass tests (Tsai, 2004), without striving for a meaningful change in their conceptual understanding.

Research on Learning from Science Texts

Given the challenges posed by characteristics of both the science text and the reader, what does past research show us about ways to facilitate the comprehension of science texts and to help students form coherent and productive knowledge structures of important science concepts?

Research on learning from science texts has largely focused on the effect of refutational texts (i.e., a text that directly refutes a commonly held misconception and provides a correct explanation). These studies, largely conducted in the late 1980s, though continued to the present, focused on conceptual change theory (Posner, Strike, Hewson, & Gertzong, 1982), and showed that refutational text compared to nonrefutational text enhanced conceptual change (see meta-review by Guzzetti, Snyder, Glass, & Garnas, 1993; Tippett, 2010). Refutational text has been shown to be effective in facilitating conceptual change, but is not typically used in science classrooms. More recently, innovative texts that support both scientific inquiry and content area literacy have been developed and have been shown to enhance learning (e.g., Cervetti et al., 2005; Magnusson & Palincsar, 2004); but again, the reach of these researcher-designed texts is limited. Far fewer studies have examined the effect of conventional or non-refutational text—specifically focusing on how conventional science texts are used in instruction and how students learn from these texts (see for example, Roth 1985a, 1990 and Roth & Anderson, 1988).

A number of studies have investigated the effectiveness of content area literacy strategies on learning from (conventional) science texts—notably, teaching students to identify text structures (Williams, Hall, Lauer, Stafford, DeSisto, & deCani, 2005); to use aids such as concept maps and anticipation guides (Textual Tools Study Group, 2006); or to use metacognitive strategies (Best et al., 2005; Chi, de Leeuw, Chiu, & LaVancher, 1994). Research indicates that these strategies, which serve to strengthen students' reading skill or activate prior knowledge, improve students' learning from text.

Pre-reading Relevance Instructions

Aside from supporting reading skill or prior knowledge, another way to facilitate more effective learning from science texts—particularly key concepts and overarching main ideas—may be in the form of pre-reading instructions. Recently, researchers have revived interest in how *contextual* factors influence how students learn from text (McCrudden et al., 2011). The nature and purpose of the reading task can significantly affect what students take away from their reading. Research suggests that externally provided instructional goals are a strong component in shaping students' goals for learning and what they ultimately learn (e.g., see review by McCrudden & Schraw, 2007). These externally provided goals are also called relevance instructions in the literature, and are described in further detail below.

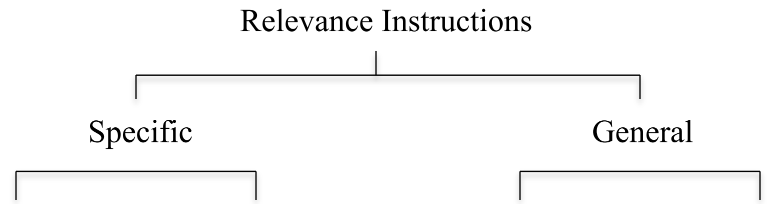
The use of relevance instructions may prove particularly relevant when reading science texts because of students' low levels of topic knowledge. Part of effective academic reading involves extracting the main ideas and details that are relevant to the discipline. This core literacy skill has been increasingly emphasized, especially with the publication of the Common Core State Standards for English Language Arts and Literacy in History/Social Studies, Science and Technical Subjects [Council of Chief State School Officers (CCSSO) & National Governors Association (NGA), 2010; corestandards.org]. But as alluded to in the previous section, students with low topic knowledge may not readily grasp which ideas are significant. Thus, relevance instructions may orient students to the scientifically important ideas in the text. This problem is further exacerbated by students' conceptions of learning science—seeing it as an accumulation of facts and details about science concepts instead of as the construction of coherent descriptions and explanations of the natural world. Later in this chapter further information is presented on how relevance instructions designed from a disciplinary perspective might facilitate the learning of science concepts in a more coherent, integrated, and ultimately, more productive manner.

Definition and types of relevance instructions. Relevance instructions are instructor-provided cues that identify which material in the text is important or relevant to a particular reading task (McCrudden et al., 2010). These instructions can be provided verbally or in text, and include instructional aids such as learning objectives and textbook adjunct questions.

Examples from an ecology chapter of a major textbook include: What is ecology? What are primary producers? How do consumers obtain energy and nutrients? and How does energy flow through ecosystems? (Miller & Levine, 2010).

Relevance instructions facilitate learning in several ways: (1) they define or clarify a purpose for reading that is related to the task at hand, (2) they orient the reader to the information that is most relevant to those goals, and (3) they provide more specific criteria for what the form of learning should look like (e.g. a term, a list of characteristics, or an explanation). Students then devote more attention and cognitive resources to attaining those learning goals.

In their review, McCrudden and Schraw (2007) categorized relevance instructions into two main categories—general and specific—largely based on the amount of information targeted by the instruction (see Figure 2.1).



	Targeted Segments	Elaborative Questions	Perspective	Purpose
Definition:	Prompts that target discrete text segments	Prompts that promote explanatory inference	Prompts that ask readers to view a text from a designated point of reference	Prompts that ask readers to read for a general reason

Figure 2.1. Taxonomy of Relevance Instructions (from McCrudden et al., 2010)

General relevance instructions include both *general purpose instructions* and *perspective instructions.* They orient the reader by providing a general purpose or perspective from which to read the text. Examples include “Read in order to be able to write a summary” or “Read from the perspective of a British soldier during the American Revolution.” They “prompt readers to focus on broad categories of information or to engage in reading behaviors based on a particular reading context" or "by invoking a particular schema" (McCrudden & Schraw, 2007, p. 123). Specific relevance instructions target more specific segments of the text ranging from single words to chunks of text. McCrudden and Schraw distinguished two types of specific instructions based on the amount of information that is targeted and the cognitive processing required to answer the question: *targeted segment questions* and *elaborative interrogation questions.* The former focuses the reader's attention on a specific piece of information, usually a term or a proposition that is explicit in the text (e.g., What is Japan's economy based on?). In contrast, elaborative interrogation questions "prompt readers to use their background knowledge to elaborate on specific information within the text" (p. 120). Often in the form of "why" questions, they require inferential thinking to obtain the answer (e.g., Why do many desert animals sleep during the day?). They are thought to enhance learning by prompting the reader to make connections between the text and their own understanding, which theoretically facilitates understanding (W. Kintsch, 1998).

Relevance instructions can appear in different forms, written as questions or statements. Both the question "What are the three types of biodiversity?" and the directive "List the three types of biodiversity" orient the reader to the same information in the text. Relevance instructions can also occur at the beginning, end, or within a text in the form of adjunct questions. Because I was interested in how a learner's *initial* goals affect their reading strategies and what they ultimately learn from reading text, this study only concerns relevance instructions that occur at the outset of reading (i.e., learning objectives or pre-reading questions).

The Effect of Relevance Instructions on Learning

What has research shown about the effect of pre-reading relevance instructions on learning from text in general, especially on factual (retention) versus conceptual learning? Are there particular learning outcomes associated with the different types of relevance instructions? Answers to these questions would help us better predict the effects of relevance instructions that are designed to promote coherent and integrated scientific understandings. I will first review research on general instructions—i.e., purpose and perspective instructions, and then turn to more specific ones, such as elaborative interrogation and targeted segment questions.

General purpose relevance instructions. A number of studies have investigated how general purpose relevance instructions affect text-processing behaviors or strategies and learning from text (e.g., Linderholm & van den Broek, 2002; Narvaez, van den Broek, & Ruiz, 1999; Van den Broek, Lorch et al., 2001). Many of these studies contrasted the effects of very divergent reading purposes, such as to study for an exam versus to read for entertainment. For example, Broek, Lorch et al. (2001) studied the effect of readers' goals on inference generation (captured through think-alouds) and recall using college students who were told to read with a study purpose or an entertainment purpose (e.g., to imagine they were preparing for an essay exam, vs. to imagine that they had come across an interesting magazine article). They found that students in the study condition focused more on building coherence using explanatory and predictive inferences (confirming results by Navaez et al., 1999), and that they paraphrased and repeated text more often. Students reading for entertainment produced more associations and evaluations of the text, but these comments tended to be unrelated to the core ideas of the text. Students in the study condition also demonstrated better recall of the text. The few studies on more nuanced types of general purpose instructions—such as to "explain", "summarize", or "discuss"—have also shown that students modify their reading strategies based on the given purpose for reading (e.g., Braten & Samuelstuen, 2004; Magliano, Trabasso, & Graesser, 1999).

These studies and others showed that an assigned general purpose can affect (1) the strategies and associated inferencing behaviors used to process the text and (2) recall of the text. In general, students with a study purpose—and more specifically, an explanation purpose—adopt strategies that focus more on building coherence (e.g., through paraphrasing or generating explanatory inferences) versus students who read for entertainment purposes.

Research on perspective relevance instructions. A number of studies have examined how instructions that assign a particular perspective to the reader (i.e., perspective relevance instructions) affect text-processing behaviors and learning (e.g., Kaakinen et al., 2002, 2003; Pichert & Anderson, 1977; Schraw, Wade, & Kardash, 1993). Although these instructions require the reader to examine the whole text, they provide more definite criteria for distinguishing relevant versus irrelevant information than general purpose instructions. Because of this, the relationship between the instruction and the learning of the targeted information can be more clearly defined.

In their seminal study, Pichert and Anderson (1977) investigated the effect of reader perspective on learning from text (measured by recall). College students read a narrative text containing a description of a house from one of three perspectives (a home buyer, a burglar, or control). They also asked students to rate the text ideas for importance. The participants showed better recall of the information that was relevant based on their assigned perspective, and also rated those segments of information as more important. Goetz, Schallert, Reynolds, and Radin (1983) replicated this study and also examined reading times for the different perspective groups. In addition to increased recall of the relevant information, they found that students spent more time reading the information that was relevant to their perspective, confirming the attention-focusing hypothesis (i.e., increased attention to relevant information—rather than more efficient processing of the information—leads to increased retention of the material), a finding similar to that of Kaakinen et al. (2002).

Overall, research on the effect of perspective instructions shows that they promote recall of perspective-relevant information, and that the reader's attention (measured via reading times or eye tracking) is directed toward the relevant sections of the text.

Research on Specific Learning Objectives

In contrast with general relevance instructions, specific relevance instructions target specific information in the text—usually terms or concepts within one sentence or a paragraph. Whereas general relevance instructions place the burden of locating relevant information on the reader, potentially taxing cognitive resources, specific relevance instructions explicitly identifies the targeted information, which makes it easier for the reader to locate. I will first review the research on targeted segment questions, and then discuss elaborative interrogation questions.

Effect of targeted segment questions. A flurry of studies in the 1970s and 1980s investigated the effect of specific relevance instructions on verbatim learning. A number of these studies compared the influence of specific learning objectives (e.g., "Learn about the physical appearance of Gothic type") to a control, often in the form of a general learning goal (i.e., "Read to learn as much as you can"). This body of early research showed that specific relevance instructions facilitated verbatim learning, as shown by increased recall of targeted information (Frase & Kreitzberg, 1975; Kaplan, 1974; Rothkopf & Billington,1975b; Rothkopf & Billington,1979), and that the more specific the objective, the stronger the recall of the targeted information (Kaplan & Rothkopf, 1974; Rothkopf & Kaplan, 1972). In general, the reviews of research (e.g., Andre, 1979, Hamilton, 1985; and McCrudden & Schraw, 2007) show conclusively that explicit and specific learning objectives, like targeted segment questions, facilitate learning of goal-relevant information. However, several important points need to be made:

1. Specific learning objectives improve learning of relevant information, but can also suppress learning of non-targeted (i.e., irrelevant) information (e.g., Duchastel & Brown, 1974; Frase & Kreitzberg, 1975, Rothkopf & Billington, 1979). Researchers such as Duchastel and Brown (1974) referred to this as a *focusing effect*.

2. Specific learning objectives increase factual learning of the material (measured by recognition and recall) but less is known about their relationship to deeper, conceptual learning. One criticism of these early studies is that researchers viewed learning as a process of knowledge acquisition and retention and consequently assessed learning through low-level questions such as recognition and recall. In contrast, Mannes and Kintsch (1987) showed that the type of learning objective provided to a reader had different effects on recognition/recall (lower-level) versus problem-solving (higher-level learning).

Research on elaborative interrogation questions. Studies related to the fourth category of relevance instructions—elaborative interrogation questions—provide more insight into the effect of higher-level questions on student learning. These questions—usually inserted within text after a particular sentence, paragraph, or section—require readers to use their background knowledge to explain or elaborate on specific information. For example, after a paragraph describing the hibernating behavior of a bear, an elaborative interrogation question might ask “Why does a bear hibernate in the winter?” By virtue of their positioning, they do not function fully in the same way as pre-reading instructions, which serve to direct the reader’s attention to important material. However, they do encourage active processing of the relevant text, by prompting the learner to activate prior knowledge and to integrate it with the information in the text. Research on elaborative interrogation questions show that more than lower-level instructions, these higher-level questions facilitate learning, both factual and conceptual, for different age groups (Ozgungor & Guthrie, 2004; Seifert, 1993, 1994; Wood, Pressley, & Winne, 1990).

The initial questions at the outset of this section were: What has research shown about the effect of pre-reading relevance instructions on learning from text? Are there particular learning outcomes associated with the different types of relevance instructions? To summarize, research shows that relevance instructions influence text processing behaviors/strategies—often drawing attention to and increasing processing of the relevant information. They also facilitate learning (e.g., increased recall of relevant content). In general, as the relevance instruction more clearly defines the relevant information (e.g., as with perspective instructions or targeted segment instructions), it increases the learning of that specific information—often accompanied by the same recall or decreased recall of untargeted information. (Though I will discuss in the next section how the use of relevance instructions does not always lead to a decreased or no effect on learning of the untargeted information.) Higher-level cognitive instructions (e.g., to explain or "why" questions) lead to improved learning, presumably because it prompts more active processing within text elements, and between the text and the reader's prior knowledge.

The Effect of Relevance Instructions on Higher-level, Conceptual Learning

Overall, the body of literature on pre-reading relevance instructions shows that they facilitate certain types of learning, particularly memory for text as measured by recognition and recall questions. However, as mentioned earlier, the science standards documents, such as the

K-12 Framework (NRC, 2012), call for students to learn more than just facts, but to relate them meaningfully into an organized conceptual framework. Research on the effect of relevance instructions on higher-level conceptual learning has been growing. These studies (e.g., Gil, Braten, Vidal-Abarca, & Stromso, 2010; Lehman & Schraw, 2002; McCrudden et al., 2006) have used measures such as conceptual questions, application questions, or essays to evaluate the depth of processing—or how well the knowledge has been integrated into a coherent mental representation, and with the reader's background knowledge. Most of these studies have been conducted with undergraduate students.

In a number of these studies, the experimental relevance instruction drew attention to the main ideas of the text [e.g., "[Pay] particular attention to the explorers who made important discoveries and what these explorers discovered" (Lehman & Schraw, 2002, p. 741) or "On the following computer screen, you will read about how experts engage in the four components of deliberate practice" (McCrudden et al., 2006, p. 307)]. The results showed that these "main idea" relevance instructions facilitated conceptual learning (effect sizes ranging from $\eta^2 = .04$ to .076), which was measured by application questions or essays. These types of instructions may function by orienting readers to the key ideas that will enable them to construct a more coherent mental model of the text. The studies also showed that such instructions improve factual learning (measured by recognition and recall questions), especially when compared to a control group given no instructions (e.g., Harp & Mayer, 1998; McCrudden et al., 2006), or to a control group given instructions that target specific non-main idea information (McCrudden, Schraw, & Kambe, 2005). However, main idea instructions did not improve factual learning in situations where the control group was given a global instruction to "Remember as much as you can from the story" (Lehman & Schraw, 2002). Overall, pre-reading instructions directed at the main topics seem to have a positive effect on learning important ideas, as well as enhance conceptual and factual learning of the text as a whole.

Research on Higher-level Instructions that Promote Integrated Knowledge

The experiments described in the previous section measured the effect of relevance instructions on deeper comprehension or higher-level learning (using measures like application questions or essays). However, the relevance instructions that were used [except for the "explain" question in the Harp and Mayer (1998) study] simply directed the reader's attention to the main ideas of the text. They did not explicitly prompt for higher-level, integrative processing of information. Within the general taxonomy of relevance questions, the elaborative interrogation question explicitly prompts for higher-level reasoning, but only for a limited portion of the text. General purpose instructions such as "Learn as much as you can" could possibly, but not necessarily, prompt students to process the information at a deeper level.

One way to encourage deeper processing of the text might be to ask students to *explain* a topic at the global level, or to form an argument. A reader asked to explain a topic may seek to understand how information in the text is related to one another and make more causal inference, which is also associated with stronger recall (Graesser et al., 1994). Likewise, a reader who is asked to form an argument must actively evaluate information as well as reorganize the information to support their claims. The activation of these higher-level processes may promote the formation of a situation model—i.e., a representation of the text that is more thoroughly integrated with the reader's prior knowledge, resulting in deeper conceptual learning as well as improved memory for the information (as seen in Magliano et al., 1999).

Effect of higher-level instructions on learning: **To summarize, explain or form an argument** Emerging research on the comprehension of multiple documents has provided useful insights into the effect of higher-level instructions—that is, those that explicitly prompt for higher-level integrative processing of the text. Through a series of studies, Cerdan, Vidal-Abarca, and colleagues showed that high-level questions designed to promote integration of different segments of material from different text sources (or from different paragraphs within a long text) resulted in deeper learning compared to questions that focused on specific (and important) aspects of the topic (e.g. Cerdan & Vidal-Abarca, 2008; Cerdan et al., 2009). Significantly, there were no significant differences in the performance of students on more shallow levels of learning.

Other studies have compared the effects of summarizing versus forming an argument. To form a summary, a reader must identify the main ideas, omit minor or redundant details, and collapse the information into a coherent framework (Brown & Day, 1983; van Dijk & Kintsch, 1983). Research shows that summarizing text is linked to stronger comprehension (Brown, Bransford, Ferrara & Campione, 1983; Leon & Escudero, 2015). In order to summarize, students must actively integrate information in building their representation of the text, also making the information more accessible and useable for future use (Rinehart, Stahl, & Erickson, 1986; Wade-Stein & E. Kintsch, 2004).

Constructing an argument, on the other hand, allows for *transformation* of knowledge—that is, the combining of information in the text with information from the reader's background knowledge or the combining of text information in a new way (Wiley & Voss, 1999). Theoretically, the deeper connections formed can result in a more enduring, yet flexible, knowledge structure. A survey of recent studies indicates that different types of higher-level, integrative instructions (i.e., summary versus argument instructions) work best under different contexts for different readers (e.g., those with low or high prior knowledge).

For example, Wiley and Voss (1999) found that students asked to summarize performed better on the recognition test, but that higher-level instructions—particularly constructing arguments and to a lesser degree explanations—resulted in more integrated and transformed understandings of the content (measured by an essay and conceptual questions). Other studies showed no difference between students asked to form a summary or argument (Braten & Stromso, 2009), or that students in the summarizing condition performed better on both recognition tests and measures of deeper learning (Gil et al., 2010).

Overall, research shows that using instructions or questions that prompt for higher-level processing (e.g., asking students to summarize, explain, or form an argument) is associated with deeper and more integrated learning (Harp & Mayer, 1998; Magliano et al., 1999, Wiley & Voss, 1999). However, the effectiveness of the specific types of higher-level instructions has not been consistent, and likely depends on different contextual and reader factors, such as prior knowledge (e.g., Gil et al., 2010). More research is needed on instructions that encourage deeper-level processing of the text at a global level.

The Interaction of Reading Skill and Relevance Instructions

In addition to considering the main effect of relevance instructions, some studies have investigated whether its effects are moderated by text factors (e.g., text with low or high coherence; Lehman & Schraw, 2002) or reader factors, such as reading skill (Reynolds et al., 1993; van den Broek, Tzeng, et al., 2001) or working memory capacity (Di Vesta & Di Cintio,1997; Linderholm & van den Broek, 2002). For the research reported here, I sought to determine whether students' reading skill interacted with the relevance instruction intervention. Reading (or comprehension) skill is closely related to reader characteristics such as verbal ability. It may also relate to factors such as working memory capacity (WMC), since differences in WMC may affect the amount of cognitive resources one can expend on temporary storage and retrieval of information, as well as on processing (Just & Carpenter, 1992).

A review of the literature shows that relevance instructions have different effects on students with differing reading abilities, yet studies are sparse and are at times conflicting—perhaps due to the age group being studied or due to different categories of relevance instructions being used. Van den Broek, Tzeng, and colleagues (2001) found that college students benefited from inserted relevance instructions, whereas younger students (e.g., fourth and seventh graders) were actually hindered in their comprehension of the text. The researchers suggested that the inserted questions competed for the limited cognitive resources of the younger students, and interfered with the formation of a coherent mental representation. Reynolds and colleagues (1993) found that targeted relevance instructions benefited more-skilled sixth graders, but hindered the recall of less-skilled sixth graders relative to the less-skilled readers in the control group (who were asked to remember main ideas). In this study, reading skill was determined by students' reading score on a standardized achievement test.

Other studies have used WMC as a proxy for reading skill (although they are not directly related to one another). The study of undergraduates by Linderholm and van den Broek (2002) suggested that general purpose relevance instructions influence the reading strategies of both high- and low-WMC readers, but that low-WMC readers are less effective in their processing of the text, which leads to lower recall. Lastly, studies investigating the effect of perspective relevance instructions and WMC on (recall) learning did not show any interaction between the two factors (Di Vesta & Di Cintio, 1997; Kaakinen et al., 2002, 2003), although the studies by Kaakinen et al., 2002, 2003 revealed that students with low-WMC engaged in less efficient reading strategies than those with high-WMC.

Overall, targeted segment instructions seem to benefit high-skilled readers more than low-skilled readers (e.g., Reynolds et al. 1993) whereas perspective instructions do not benefit low- or high-WMC readers more than the other (Di Vesta & Di Cintio, 1997; Kaakinen et al. 2002, 2003). More studies are needed to confirm these findings and to determine whether specific types of relevance instructions are moderated in characteristic ways by the reader's comprehension skill or WMC.

Rationale for Disciplinary Relevance Instructions

The K-12 Framework states that "students need sustained practice and support to develop the ability to extract meaning of scientific text from books, media reports and other forms of scientific communication" (NRC, 2012, p. 76). Given our increased understanding of relevance instructions and their effects on learning, can they be effectively used to support, or enhance, student comprehension of science texts? Is there a way they should be designed that would facilitate a coherent, integrated understanding of the concepts included in a science text? I propose that such instructions would include three important components.

First, the pre-reading relevance instructions should focus on the important scientific ideas in the text. Students with low prior knowledge and tenuous domain knowledge would benefit from relevance instructions that draw attention to the main ideas of the topic, and ideally, in relation to the core ideas of the discipline that are outlined in the standards documents (Duschl et al., 2007; NRC, 2012). For example, the K-12 Framework describes "cross-cutting concepts"—the critical ideas in science that help to explain a variety of phenomena and which are foundational for developing conceptual understanding in various science disciplines. They include concepts such as cause-and-effect mechanisms, structures and their related functions, and the integration of parts and processes into systems (Cross-cutting Concepts 6, 2, and 4 from

NRC, 2012, p. 84). The K-12 Framework also describes Core Ideas from the disciplines that students should be expected to know and understand, which have been incorporated into the performance expectations of the Next Generation Science Standards (NGSS Lead States, 2013). Relevance instructions should cue the importance of topic information that connects with these types of big ideas.

Another point to consider is that pre-reading relevance instructions should, ideally, be aligned with the goals of the discipline itself. One goal of science is to provide explanations of natural phenomena—or to link scientific observations to the underlying chain of cause and effect (NRC, 2012, pp. 66-67). Within the disciplinary practice of "obtaining, evaluating, and communicating information," the K-12 Framework also states that students should be able to "read scientific and engineering text commensurate with their scientific knowledge and explain the key ideas being communicated" (NRC, 2012, p. 76). Thus, relevance instructions that direct students to *explain* the content of the text—which is often itself a description or explanation of natural phenomena, would prompt them to engage in one of the primary practices of the discipline. An explanation of natural phenomena usually includes several subparts: an observation or description of the phenomena, descriptions of the cause and effect mechanisms, and logical reasoning of how they are linked (Chambliss, 2002; McNeill & Krajcik, 2007).

This leads to the third component—that science-aligned relevance instructions should encourage readers to form a coherent and integrated understanding of the content. Relevance instructions that ask students to explain a topic may help to overcome a common problem that students display when reading texts—that is, they tend to focus on facts rather than on forming integrated understandings. The purpose of academic science texts is usually to communicate a principled body of content knowledge, rather than discrete facts. Yet, specific relevance instructions, and even the perspective instruction to some degree, seem to encourage the learning of pieces of information, rather than helping students to understand the material more holistically.

As described earlier, research on higher-level instructions suggests that directing students to summarize, explain, or to form an argument helps them to form more coherent and integrated representations. Research in science education also suggests a strong link between conceptual understanding of ideas and the ability to explain them (McNeill & Krajcik, 2007; Sutherland, Shin, & Krajcik, 2010). Sutherland and her colleagues noted that a learner's content knowledge went hand in hand with the quality of the student's explanation. Thus, pre-reading instructions that prompt students to generate explanations of a particular topic may help them to integrate main ideas and details and help them to form a coherent mental representation of the content that is associated with higher-level conceptual learning.

Pre-reading questions that typically appear in current science textbooks show that they often don't align with these ideals. Most are targeted segment questions that focus on facts, concepts and processes, with an occasional elaborative interrogation question (e.g., "What are three types of biodiversity? Why is biodiversity important? and What are direct and indirect values of biodiversity?" (Here, the "why" question is not a true elaborative interrogation question, since the information needed to answer the questions is provided explicitly in the text.) Overall, these learning objectives are intended to focus the reader's attention on discrete, albeit important, portions of the text, without necessarily helping readers to develop a macro-level understanding of the material.

A learning objective that would encourage a more integrated and deeper understanding of the topic of biodiversity could be the following: "Explain why the different types of biodiversity (genetic, species, and ecosystem diversity) are so important to the survival of different species on earth?" This type of objective identifies the natural phenomena (biodiversity) in terms that make clear its significance (how it relates to the survival of different species). It also requires students to use reasoning to restructure the important facts from the entire text into a coherent explanation, and thus may facilitate deeper learning.

Research Gaps and Goals for This Study

In their review of studies on relevance instructions, Ramsay and Sperling (2011) noted that more research was needed on relevance instructions that went beyond the four prototypes described by McCrudden and Schraw (2007) (i.e., general purpose, perspective, targeted segment, and elaborative interrogation). I suggest that relevance instructions can be refined so that they align with the purposes and practices of particular academic disciplines. In the previous section, I described how relevance instructions might be tailored to enhance the comprehension of science texts: they should draw students' attention to the main ideas related to the scientific concepts; prompt for explanations; and encourage the construction of a robust, holistic representation of the content. This type of science-aligned instruction does not readily fall within any of the relevance instruction categories.

A number of studies described above have employed relevance instructions that reflect these characteristics (e.g., they have prompted for an explanation)—notably, Braten and Stromso (2009), Cerdan and Vidal-Abarca (2008), Gil et al., (2010); and Harp and Mayer (1997). However, I would argue that more studies on such relevance instructions are needed for a couple reasons. One primary reason is that the majority of research, such as the studies listed above, has been conducted using college students. In contrast, notably fewer studies have examined how relevance instructions influence the reading of primary or secondary school students [e.g., the series of studies by Rothkopf and colleagues (1972, 1974, and 1979) using high school students; Braten & Samuelstuen, 2004; and Vidal-Abarca, Gilabert, & Rouet, 1998]. Students are increasingly exposed to academic expository text in lower elementary grades (Lee & Spratley, 2009), yet compared to college students, elementary and high school students have less background knowledge (domain-knowledge, and knowledge of discourse conventions) to support their comprehension of expository texts, including science texts (e.g., see reviews by Best et al., 2005; Fox, 2009; Ray & Meyer, 2011). Research has also shown that college students are fairly fluent readers or are proficient in their use of reading strategies, whereas younger readers have more difficulty identifying important ideas (Garner et al., 1989), and are less likely to use comprehension strategies (e.g., comprehension-monitoring) when reading difficult texts (e.g., Beck, McKeown, Sinatra & Loxterman, 1991; Vidal-Abarca, Martinez, & Gilabert, 2000). Thus, it is important to investigate the effect of different types of pre-reading instructions on younger students and to determine which form(s) would maximize their conceptual learning.

On a related note, more research is needed on the effectiveness of pre-reading instructions for students of differing reading abilities within a given age group or grade level. The research on relevance instructions and reader factors such as reading skill, WMC, or prior knowledge is sparse. The studies reviewed in the previous section tenuously support the notion that relevance instructions provide no or some advantage to higher-skilled readers, who have enough cognitive resources (i.e., memory and processing capacity) and reading strategies to instantiate the relevance instructions. However, an alternate hypothesis is that the relevance instruction may prompt lower-skilled students to focus on content or adopt processing strategies that would already be executed by higher-skilled readers, thus providing more benefit for lower-skilled readers. More studies are needed to investigate this question of how relevance instructions interact with reader characteristics.

Research Questions

Given the gaps in the body of literature, my study sought to examine the effects of three different types of pre-reading instructions (with two instructions aligned to the discipline of science) on middle school students' comprehension of science texts. I also sought to investigate how reading skill might moderate the effect of the instructions. My research questions were as follows:

1. How do the following types of relevance instructions compare in terms of their effects on the factual learning, the learning of main ideas, and the conceptual learning of middle school students reading a science text on the topic of sweetness:

    a. an instruction that prompts students for best understanding;

    b. an instruction that prompts students to form a holistic explanation of the topic; and

    c. an instruction that prompts students to focus on the core scientific idea of the relationship between structure and function.

2. What differences can be observed among low-, average-, and high-skilled readers in relation to the use of science-specific relevance instructions?

3. Are there differences among the three relevance instruction groups in terms of the specific types of main ideas that are learned (e.g., main ideas related to the process of tasting versus those related to the receptor mechanism)?

4. How much of a role do reading skill and prior knowledge have, compared to relevance instructions, with respect to student performance on the learning measures?

In the following three chapters, I describe the methodology I used for my study, review my findings, and discuss the results and significance of those findings.

METHODOLOGY AND METHODS

Experimental Design

This research was a quantitative investigative study to compare the effects of three different relevance instruction conditions on learning from a science text. The three conditions were (a) a generic instruction—to read for best understanding; (b) a general relevance instruction that prompted for an integrated explanation (explanation RI); and (c) a higher-level relevance instruction that targeted a core scientific idea in the text (structure-function RI).

Participants

Fifty students in grades six through eight participated in the study (64% female and 36% male). Most of the students ($n = 48$) were recruited from the afterschool programs of seven New York City urban public schools. Students were recruited from afterschool programs because the New York City Department of Education does not allow non-instructional research to be conducted during regular school hours. (See Table 3.1 for a brief comparison of the demographics of the schools. See also Appendices A and B for the recruitment procedure and consent forms used in the study.) Two students who attended private schools were recruited through personal acquaintances. There was a wide range of schools represented by the participants in the study. However, since students were asked to complete a norm-referenced standardized reading test, in addition to a test of prior science knowledge, the variation in the school background of the participants was controlled for through random assignment and verified using one-way ANOVA. All students spoke English as a first language except for one ESL student, who spoke Portuguese.

Table 3.1

A Comparison of Participants' Schools

	School A	School B	School C	School D	School E	School F	School G	Private school students
Number of participants	8	6	6	9	6	9	4	2
Total students; Grades	1038 6-9	504 PreK-8	661 6-12	557 6-12	1606 6-8	338 6-8	670 5-12	*
% Ethnicities:								
African-Am	8%	27%	49%	49%	13%	26%	55%	*
Hisp/Latino	27%	13%	15%	12%	43%	38%	43%	
Asian	31%	49%	29%	31%	37%	7%	1%	
White	30%	8%	1%	2%	6%	26%	1%	
ELL	10%	5%	8%	3%	18%	1%	6%	
Special needs	15%	11%	20%	7%	16%	16%	27%	
Eligible for free lunch or reduced-price lunch	45%	39%	74%	58%	71%	50%	69%	*
Student attendance rate	95%	97%	95%	96%	93%	96%	95%	*
English / Math NY State test scores	44% / 49%	59% / 70%	21% / 24%	57% / 50%	32% / 30%	59% / 63%	28% / 42%	*

* Data not included

Materials

Text. For this experiment, I used a 384-word passage titled “Sense of Sweet” (see Appendix C). The text was adapted from the article *Sense of Sweet: It All Starts with the Tongue* (Miller, 2012) found in *Odyssey Magazine*, a science magazine that targets students in grades 5 – 10. (*Odyssey Magazine* has since been merged into *Muse Magazine*, published by Cricket Media.) The text’s Flesch-Kincaid reading level was 6.7 (Flesch, 1948; Kincaid, Fishburne, Rogers, & Chisson, 1975), determined using Coh-Metrix—an online tool used to analyze various linguistic features of text (Graesser, McNamara, Louwerse, & Cai, 2004). In the introductory paragraph, the author’s purpose—to explain how we are able to taste sweetness—is posed as a guiding question, with each subsequent paragraph providing descriptions of various processes, structures, and key mechanisms that are important to our ability to sense sweetness.

I selected this passage to fulfill four main criteria: (a) to contain unfamiliar, technical content about biological structures and processes so as to be representative of the type of science text that students encounter, and (b) to minimize the possibility of students’ prior knowledge of the topic; (c) to be written at a grade level and style geared toward middle school students (i.e., high in coherence and readability) so that students would make a meaningful attempt to read the text despite the number of new terms and concepts. Research shows that strong text coherence is highly correlated with reader interest, which is a significant mediator of the learning that occurs from the text (Schraw et al., 2001). Lastly, (d) the figures were deleted from the text, so that the results would not be confounded by the students’ ability to learn from scientific diagrams (e.g., Mayer, 1993). In the article, there was a diagram of the onion-shaped taste bud and internal taste cells. However, there were no figures that illustrated a sweet receptor or how the sweet receptor fit together with the sweet food molecule.

Relevance instructions. Participants in each condition received a specific relevance instruction in written form, which was placed directly above the experimental text. Table 3.2 below describes the three experimental groups and the specific relevance instruction they received.

Table 3.2

Description of the Experimental Relevance Instructions (RIs)

Type of relevance instruction	Group 1 Generic RI	Group 2 Explanation RI	Group 3 Structure-function RI
Purpose	Intended to elicit "best effort" understanding.	Intended to promote the construction of an integrated, coherent explanation.	Intended to promote higher-level learning of a core disciplinary idea.
Wording	Please read the article and try to understand it as well as you can. You will be asked to write what you learned.	Please read the article and try to understand it as well as you can. Overall, you should be able to *explain how we are able to taste sweetness.* You will be asked to write what you learned.	Please read the article and try to understand it as well as you can. Overall, you should be able to *explain how the structure of sweet receptors is important to how they work.* You will be asked to write what you learned.

To ensure that students actually read the instructions, the following line was included after the relevance instruction: "Draw a small star in the upper right corner of this page so that I know you have read these instructions."

Control Measures

I included two measures to ensure that the three experimental groups were equivalent in their reading skill and background knowledge.

Test of reading skill: Gates-MacGinitie Reading Test (GMRT). As mentioned in the literature review, reading skill is a significant factor that influences reading comprehension. I used the Gates-MacGinitie Reading Test, 4th ed. (GMRT; MacGinitie, MacGinitie, Maria, & Dreyer, 2000), a norm-referenced standardized test, to measure and control for this variable. Form T, designated for grade levels 7 – 9, contains two sections: a 45-question vocabulary test, which students have 20 minutes to complete; and a reading comprehension section of eight passages (four fiction and four nonfiction) with a total of 48 questions (four to six questions per passage). Students had 35 minutes to complete this section. Among various standardized reading tests, the GMRT has been extensively reviewed for its validity and reliability (see, for example, Collaborative Center for Literacy Development, Adolescent Literacy Assessment Evaluation Tool; Johnson, 2005). However, as with most of the standardized tests available on the market, there is only "partial evidence" of it being culturally sensitive. For example, Cintavey (1989) examined the effect of race and gender on performance on the GMRT and found that these two factors did not have a significant effect, although the sample size was very small (n = 33). More specifically, the test developers performed a differential item functioning analysis and, with the input of "cultural consultants," eliminated items that raised concerns about bias (Johnson, 2005). The text developers have not, however, provided norming tables that are "disaggregated for different ethnicities or cultures."

I also used total reading scores from the GMRT to create categories of low-, average-, and high-skilled readers, using the tercile-split method described in a later section.

Test of prior knowledge: Prior Knowledge Questionnaire (PKQ). I assessed prior knowledge using ten open-ended items that tapped into students' topic-knowledge, domain-knowledge, and knowledge of academic vocabulary that was relevant to the text (see Appendix

D). The first four questions were used to determine students' topic knowledge of tasting, including any knowledge of the underlying mechanism (i.e., of the taste receptors). The questions were open-ended and worded so as not to provide any information found in the science passage. The remaining six questions assessed domain knowledge—particularly of scientific terms and concepts that appeared in the passage (e.g., molecule, cell, and conform). Although these vocabulary words were found in the passage, the prior knowledge questions referred to them more generally, and did not describe them in relation to the process of tasting sweetness. Overall, the administration of the prior knowledge questionnaire prior to the experiment did not likely contribute to any learning reflected in the experimental test. The assessment of prior knowledge was meant to serve as contextual data—to confirm the expected lack of knowledge on the part of students of the molecular mechanism underlying our ability to taste sweetness.

Measures of Learning

"Learning" was classified into two categories: factual learning (i.e., memory of facts) and conceptual learning (i.e., integration of information into a coherent situation model or mental model). I assessed learning using three different types of self-developed instruments: a free recall (Part 1), a four-item short-answer performance test (Part 2), and a combined multiple-choice, short-answer test (MC/SA) (Part 3) (see Appendix C). Factual learning was assessed using recognition and structured recall (i.e., short-answer) questions in the MC/SA, as well as through the free recall. Conceptual learning was assessed using all three parts, through the higher-level questions in the MC/SA, the short-answer performance test, and the overall quality of the recall.

The test questions were developed partly based on E. Kintsch's (2005) categorization of shallow- and deep-level questions (also called low- and high-level), as well as on the categorizations described by Chi and colleagues (1994) and Goldman and Duran (1988). In sum, different types of questions form a continuum in terms of capturing a range of learning. Verbatim questions tap into shallow levels of learning, and require learners to recognize or recall specific facts or details that are explicit in the text. Questions that call for summarizing or paraphrasing also assess students' learning of the textbase, but at a macro-level. In contrast, high-level questions require learners to make more far-reaching connections (or global inferences) of the text's content, to apply the content in new contexts, or to form new connections with the content and the learners' personal knowledge base. These questions are thought to tap a reader's situation model of the content. Goldman and Duran (1988) classified questions into five categories based on the reader's level of processing. The first three were versions of verbatim questions; the fourth type required integration across paragraphs, which required higher-level inferencing and integration skills; and the fifth type required reasoning and application.

In this study, I measured factual learning using verbatim questions, which focused on single concepts or propositions that were explicit in the text. I measured conceptual learning using high-level questions, along the lines of Goldman and Duran's Type Four or Type Five questions, which required application or global integration of the text's content.

Part 1: Free recall. Free recall is a commonly employed measure of learning in literacy research (e.g., see review in Fuchs, Fuchs, & Maxwell, 1988) as well as in research on relevance instructions (e.g., see review by McCrudden et al., 2007). For this study, students were asked: "Please write what you learned from this article. Include as much detail that you remember from the text as possible." Although recalls are commonly used to measure students' memory for the text (i.e., factual learning), its open-ended format allows the structure of the students' conceptual representation to be captured, and thus provides a means for assessing conceptual learning as well.

Factual learning. I analyzed the experimental text, *Sense of Sweet,* using a set of guidelines that were based on principles of expository text analysis by Meyer (1985) and Mayer (1985). I identified a total of 76 idea units, which were included in a rubric that was used to score students' free recalls. An idea unit typically consisted of a predicate clause (a verb and the surrounding adjunct words), but could also be a descriptive phrase, or a specific term. (See Appendices E and F for the Free Recall Rubric and a detailed description of the guidelines used to develop it.) When scoring recalls, I examined student protocols for idea units that matched—or which provided the substantive gist of—the idea units in the rubric. The total number of idea units in student recalls served as one measure of factual learning.

The learning of main ideas and less-essential details. Since the experimental pre-reading instructions were designed to orient students' attention to important ideas in the text, I also counted the number of important ideas found in student recalls using a separate Main Ideas Rubric (see Appendix G). I created the Main Ideas Rubric using Meyer's system of text analysis (Meyer, 1985) and Chambliss' framework for explanations (Chambliss, 2002). Using their principles, I arranged the idea units of the text into a hierarchy based on their structural importance (i.e., how necessary they were to understanding the main ideas of the text). There were four levels: main ideas, important details, less important details, and least important details. When scoring for the presence of main ideas, I counted any idea unit from level 1 or 2 as an "Important Idea." I counted any idea unit from level 3 or 4 as a "Less-essential Detail". (See Appendices G and H for the Main Ideas Rubric and a full description of how it was constructed.)

Using this method, 32 idea units were categorized as “Important Ideas” and 44 as “Less-essential Details.” One more category of “Important Ideas Related to Sweet Receptors” was created during the analysis of results. This category consisted of 19 ideas units, drawn from Paragraphs 1, 2, 4, and 5. The reason I omitted the main ideas from Paragraph 3 was that those related more to the general concept of tastes, rather than sweet receptors. I hypothesized that the relevance instructions would reveal more of an effect on concepts that directly related to sweet receptors and their mechanism, and wanted to be able to detect this effect, if it were present.

As a check of validity, the Main Ideas Rubric was reviewed by two reviewers. One was a graduate student at Teachers College working in the field of literacy and text structure, and the other a high school science teacher with ten years of teaching experience. The graduate student was asked to review the propositional analysis of the text structure and the resulting hierarchy of ideas. The high school teacher was asked to review the rubric through a science disciplinary lens—to review whether the hierarchy of idea units reflected the instructional importance of those ideas relative to the topic of tasting.

Conceptual learning and free recall rubric. The free recall can also reflect the structure and coherence of a student’s knowledge, and thus serve as a measure of conceptual learning. Thus, I developed a holistic rubric that could be used to evaluate the quality of the student’s overall mental model of the content as reflected in the recall. The rubric evaluated student protocols for the following characteristics:

1. inclusion of structurally important (or main) ideas;
2. explanatory coherence of the answer—reflected by (a) the inclusion of the important steps in the mechanism of tasting sweetness and (b) connections among these steps

reflected by the organization of the ideas (e.g., steps in a sequence) or by explicit causal terms (e.g., because of, leads to);

3. integration and elaborateness—the amount of detail that is provided to support the main ideas; and

4. accuracy of ideas.

I created the categories of the rubric based on a taxonomy developed by Tabaoda (2003) and Guthrie and Scafiddi (2004) that categorized the quality of student responses based on the organization of information. In their taxonomy, the lowest levels of knowledge are characterized by isolated facts or lists of facts. In contrast, higher levels of understanding are reflected by increasing connections between facts to form concepts or interrelationships between concepts. The highest levels of knowledge reflect "coherently organized relationships among concepts that are supported by factual details" or a "well-supported explanation of the essential relationships in the topic" (Tabaoda, 2003, p. 161).

I modified the categories of knowledge in the rubric developed by Tabaoda (2003) to reflect the goal of the reading task in this study—for students to form an accurate and coherent explanation—and corresponding mental model—of tasting sweetness. I assigned the categories to a five-point scale. From the lowest to highest level, they are: (0) Incorrect facts; (1) Unassociated facts or concepts; (2) Rudimentary (or basic) explanation; (3) Partial explanation; and (4) Complete explanation. The degree of elaboration was indicated by the addition of 0.5 points. For example, a simple partial explanation scored 3.0 points, whereas an elaborated partial explanation scored 3.5 points.

The general characteristics of each level in the holistic recall rubric are provided in Table 3.3 on the following page.

Table 3.3

Levels in the Holistic Rubric and Their General Characteristics[a]

Level	**General characteristics of the explanation—degree of coherence (includes completeness and causality), accuracy, and elaborateness**
4.5 Complete explanation, elaborated	Presents a rich, coherent, and comprehensive explanation that is accurate. Demonstrates understanding of the causal mechanism underlying the phenomenon and includes elaborated information about the supporting concepts.
4 Complete explanation, simple	Demonstrates a complete understanding of the process of tasting sweet. Presents information in a coherent manner that demonstrates understanding of the causal mechanism, including key supporting details (i.e., the recognition based on shape).
3.5 Partial explanation, elaborated	Presents components of an explanation that are highly elaborated, yet is missing a critical supporting detail in describing the causal mechanism (i.e., the recognition based on shape) or does not clearly demonstrate knowledge of causal mechanism.
3 Partial explanation, simple	Demonstrates a partial understanding of the process involved in sensing sweet. Presents components of an explanation, including the involvement of the receptors, but does not clearly describe the mechanism involved (i.e., the recognition based on shape).
2.5 Basic explanation, elaborated	Demonstrates rudimentary understanding of the process involved in sensing sweet, but includes more elaborated information. Presents simple components of an explanation, yet is missing critical supporting details, such as the receptor's role.
2 Basic explanation, simple	Demonstrates rudimentary understanding of the process involved in sensing sweet. Presents simple components of an explanation, yet is missing critical supporting details, such as the receptor's role.
1.5 Unassociated concepts	Presents a concept or multiple concepts that are elaborated, but the concepts are not directly related to each other. Does not organize ideas in a way that suggests an explanation.
1 Unassociated facts	Lists facts or pieces of information, but does not show underlying organization or relationship between the facts. Demonstrates no understanding of causal process or mechanism.
0 Inaccurate facts	Presents inaccurate facts or concepts based on a misreading of the text or prior misconceptions.

[a] The General Characteristics are paraphrased from the rubric in Appendix I.

The key distinction between Level 1 (Unassociated facts or concepts), and the remaining Levels 2 through 4 is that answers in the higher levels include signs of an explanation, i.e, the presence of connective or causal conjunctions (e.g., because of, due to, then) or a description that implied causality (e.g, a description of a sequence or process). The complete rubric can be found in Appendix I.

Part 2: Short-answer performance questions. I used four short-answer questions to assess students' conceptual learning. The first two questions were directly related to the relevance instructions that were used in this study. Questions A ("Explain how we are able to taste sweetness? Answer as fully as you can.") and B ("Explain how the structure of sweet receptors is important to how it works.") were performance questions because they explicitly prompted for the information and understandings that were targeted by the experimental relevance instructions. They were also conceptual questions in that they required students to use higher-level reasoning skills or to integrate information across paragraphs.

Question C ("What was a recent and important discovery about sweet receptors in animals?") was used to test students' recall and comprehension of the last paragraph. This question was meant to be conceptual in nature—to test how well students integrated the ideas in the last paragraph. However, this question sometimes elicited a verbatim type answer—which challenged the reliability of this type of question.

Question D ("Why does a lemon taste sour and not sweet? Use the word "receptor" in your answer.") was designed to tap into students' mental model and their understanding of the underlying principle of tasting sweetness. As an application question, it was meant to probe for the integration of the student's understanding with their own prior knowledge and their ability to apply the knowledge to a different, but related, situation. These short-answer items were reviewed by three science educators for their content validity (the items' content relevance and representativeness of the text).

Part 3: Multiple-choice and short-answer test (MC/SA). Participants also completed a combined multiple-choice / short-answer test, which served as an assessment of factual and conceptual learning. The test consisted of 13 questions (eight multiple-choice and five open-ended). I used this mix of question formats because the literature on reading comprehension has shown that the use of one format alone (especially multiple-choice) may not accurately capture students' understanding of the text (Manhart, 1996 cited in Ozuru et al., 2007; see also Dochy, Segers, & Buehl, 1999; Ozuru, Kurby, Briner, & McNamara, 2013). Three science teachers reviewed the items as a check of content validity. In order to evaluate the internal consistency of the questions, I obtained Cronbach's alpha coefficient using SPSS for the six factual items ($\alpha = 0.678$) and the six conceptual items ($\alpha = 0.621$). By examining the inter-item correlations among the factual questions, I found that one question (#4) had a very low correlation with the other items. That question was subsequently omitted, and the alpha coefficient for the remaining five factual questions that were used in this study was 0.743, which is an acceptable value for research purposes (Kline, 1999). Similarly, there was one conceptual item (#13) that also displayed a negative correlation with the other conceptual items. After being omitted, the alpha coefficient for the conceptual component was 0.615. Although below 0.7, this value can be deemed sufficient given (a) the small number of questions and (b) the different types of questions used to measure conceptual learning. Traditionally speaking, Cronbach's coefficient is a measure of the unidimensionality of items measuring a particular construct (Kline, 1999). However, the construct of "conceptual learning" may actually encompass a variety of constructs depending on the actual cognitive skills being tapped (e.g., analysis versus application) and the content of the items (e.g., text-based versus those that require outside knowledge).

Lastly, one of the thirteen questions (question 1) was a reading comprehension multiple-choice question. It was included to test whether students understood the author's overall purpose in writing the text. This question was not used in the final analyses because it did not directly relate to factual or conceptual learning of the content. Thus, in the final analysis of the MC/SA data, 10 of the original 13 questions were used.

Factual questions. Five of the 10 questions (three multiple-choice and two open-ended) were verbatim questions that tested for information explicitly in the text (questions 2, 3, 6, 9, and 10). An example of a multiple-choice item was: "Where are the taste receptors located? a. in taste buds, b. on sugar molecules, c. on T1R2 proteins, d. in the brain. The distractors for the multiple-choice questions were written to reflect plausible answers from the text or possible misconceptions that students might possess as a result of their prior knowledge.

An example of an open-ended question was "Describe the taste of umami." The open-ended verbatim questions tested students' learning of non-essential details, particularly the strength of students' recall of seductive details (i.e., interesting, yet non-essential information).

Conceptual questions. The remaining five items (three multiple-choice and two open-ended) tapped into students' situational understanding and were used to assess the degree of conceptual learning from the text (questions 5, 7, 8, 11, and 12). Four of the questions tested the students' ability to apply the information in the text to new scenarios. These included questions such as "What would happen if the shape of all the sweet receptors in your tongue were changed? Or, "Which of the following is the best explanation of why we are able to taste the sourness of a lemon?" These conceptual questions required students to draw upon their background knowledge as well as content in the text, and could be answered correctly if a student had formed a well-structured mental model of tasting sweet, which would enable successful inferences and predictions.

One of the open-ended questions (Explain why cats can not taste sweetness, even if they eat something sweet) tested for information that was explicit in the text, but required more inferencing over a longer segment of text in order to answer it correctly.

Initial Evaluation of Instruments

To strengthen the validity of a number of different measures used in this research, I conducted an initial evaluation using five students (one sixth-grade, one seventh-grade, and three eighth-grade students). They were asked to evaluate the text, the free recall, the short-answer performance questions, and the multiple-choice/short answer assessment. My purpose was to determine (a) whether students could finish reading the text and questions in the allotted time; (b) whether the relevance instructions and questions were understandable; and (c) whether the questions yielded answers that could be meaningfully scored and analyzed using the rubrics. I was particularly concerned about test-taking fatigue and the comprehensibility of the questions. None of the students indicated any problems with the text or the wording of the questions.

Procedure

I collected data during three afterschool sessions. I first recruited students by describing the study in a brief introductory meeting, usually one week before the first data collection session (see Appendix A for the recruitment protocol). I also gave students parent consent forms during that meeting to be returned at or before the first session (see Appendix B for a sample form).

In the first session, I reviewed the student assent forms with the participants, and then administered the vocabulary section of the GMRT. Participants had 20 minutes to complete the 45 questions, in accordance with the test protocol. After each student finished the vocabulary section, I gave him or her the Prior Knowledge Questionnaire (PKQ), and asked the student to answer the questions to the best of their ability. Students had unlimited time to complete the PKQ, although most students finished it in under ten minutes because of their limited knowledge of the process of tasting.

In the second session, students took the Reading Comprehension section of the GM. They had 35 minutes to complete the 48 questions.

In the third and final session, I gave students a sheet that corresponded to one of three experimental groups to which they had been randomly assigned: the general RI (to understand), the explanation RI, and the structure-function RI. The sheet included the relevance instruction written at the top of the page, followed by the *Sense of Sweet* text (Appendix C).

Students were assigned to the experimental groups during the initial session based on their random seating. Numbered index cards were distributed randomly, which became the identifying number of the student. In the third session, the three experimental texts were distributed in a repeating 1, 2, 3 pattern in increasing order of the identifying numbers. For example, students 1, 2, 3, 4, 5, and 6 received texts 1, 2, 3, 1, 2, and 3 respectively.

Situational interest has been shown to significantly influence learning from text. To provide some measure of control for situational interest, I provided all students the following scenario before they were allowed to read the text:

> "Today, we are going to read an article about how we are able to taste sweetness. First, what do you see here? [Hold up empty carton of vanilla ice cream.] What is this? [Students answer: Ice cream!] Now, imagine if you lost the ability to taste sweetness. What would this taste like? [Pause.] As I said, the article that you are going to read talks

> about how we taste sweetness. Please take your time reading the passage, because you won't be allowed to go back to it once you are finished."

Students were given as much time as they wanted to read the passage, although most students completed the reading between three and six minutes. (The average reading time was 4.3 minutes.) As students began reading, I checked to see whether they all drew a star in the corner of their sheet, and if not, prompted students to go back and read the instructions carefully. When finished, students raised their hands, and were given the testing materials in the following order: 1) free written recall, 2) short-answer questions, and 3) the multiple-choice/short-answer test. Students inserted the assessments into an envelope as they completed them, and were not allowed to review a previously completed assessment. I gave students unlimited time for completing the assessments. (See Appendix L for the complete data collection protocol for sessions 1, 2, and 3.)

Scoring of the Recall

Total ideas. Blind to treatment condition, I scored the recalls for the total number of idea units using the Free Recall Rubric (Appendix E). In order to establish inter-rater reliability, a second rater, blind to treatment condition, independently scored 24% of the essays (n = 12; randomly selected). It took about 45 minutes to train the rater in using the rubric and to practice scoring protocols. In the first pass of scoring independently, raters were within one idea unit 75% of the time. I revised the rubric to take into account how to score students' common misconceptions, as well as how to score commonly generated inferences. Using this revised rubric, raters again scored 12 essays independently and were in complete agreement 75% of the time (9 of 12 essays). The raters differed by one idea unit for the remaining three essays. We resolved the differences by discussion, and I re-scored the remaining essays using the revised rubric.

The idea units that were identified in each recall were used to generate a comprehensive map of the presence of idea units in all of the recalls. From this map, one could more easily visualize the recalled ideas from the text.

Important ideas. Once the idea units in the recall were identified, I tallied the total number of Important Ideas and Less-essential Details using the Main Ideas Rubric (see Appendix G) as a guide. The category of "Important Ideas" was out of a possible 32 idea units, whereas the category of "Important Ideas about Receptors" and "Less-essential Ideas" was out of a possible 19 and 44 idea units, respectively.

Holistic score. I also evaluated each recall for its coherence and elaborateness using the Holistic Rubric (Appendix I) resulting in a holistic score for each recall. A second rater independently scored 24% of the essays (n = 12; randomly selected), and achieved 83% agreement (Cohen's kappa k = 0.79). We resolved differences through discussion, and the remaining recalls were scored by me.

Scoring of the Part 2 Short-answer Performance Test

I scored the short-answer section using the Short-Answer Performance Test Rubric (Appendix J). A second rater independently scored 24% of the students' answers (n = 12; randomly selected) in order to establish reliability. For item A, raters were in agreement 72% of the time. I changed the scoring system for question A from a three-point scale to a four-point scale, to better reflect the quality of responses received for that question. Independently, we graded another randomly selected 24% of student answers with a resulting agreement of 93%, Cohen's kappa k = 0.89. We resolved the differences by discussion. The interrater reliabilities for questions B, C, and D were kappa = 1.00, 1.00, and 0.85, respectively. I re-scored the remaining papers using the revised rubric.

Scoring of the Part 3 Multiple-choice/Short-answer Test

I graded the multiple-choice questions using the answer key (see Appendix K). Each question was worth one point. I awarded partial credit for some of the short-answer questions, according to criteria outlined in the answer key (for example, questions 11 and 12).

Summary of Instruments Used to Assess Learning

Table 3.4 contains a summary of the learning outcomes, the instruments that were used to assess these outcomes, and the means of evaluating their validity and reliability.

Table 3.4

Summary of the Assessments, Measured Learning Outcomes, and Measures of Validity/Reliability

Instrument and procedure	**Learning outcome**	**Evaluation of validity and reliability**
Free Recall Total number of idea units identified using Free Recall Rubric	**Factual learning** Recall of textbase information	Interrater reliability using 24% of protocols Complete agreement 75% of time Within one idea unit 100% of time
Free Recall Number of main idea units identified using Main Ideas Rubric	**Factual/Conceptual learning** Recognition and recall of main ideas	Content validity of main ideas rubric – reviewed by two “experts” (a graduate student in the field of literacy and text structure, the other an experienced science teacher)
Free Recall Holistic Rubric score	**Conceptual learning** Accuracy and coherence of conceptual understanding; elaboration of ideas	Interrater reliability using 24% of protocols Cohen’s kappa = .79
Short-answer Performance Question A (Direct test of explanation RI)	**Conceptual learning** Coherence of explanation; Inclusion of causal mechanism	Interrater reliability using 24% of protocols Cohen’s kappa = .89

(continued)

Table 3.4

Summary of the Assessments, Measured Learning Outcomes, and Measures of Validity/Reliability (continued)

Instrument and procedure	**Learning outcome**	**Evaluation of validity and reliability**
Short-answer Performance Question B (Direct test of structure-function RI)	**Conceptual learning** Higher-level processing/analysis of key idea	Interrater reliability using 24% of protocols Cohen's kappa = 1.00
Short-answer Performance Question C	**Conceptual learning** Recall of main ideas, and inferencing over a larger segment of text	Interrater reliability using 24% of protocols Cohen's kappa = 1.00
Short-answer Performance Question D	**Conceptual learning** Application of key idea	Interrater reliability using 24% of protocols Cohen's kappa = .85
Multiple-Choice Short-Answer (MC/SA) Factual Questions (Items 2, 3, 6, 9, 10)	**Factual learning** Recognition and recall of facts	Content validity – reviewed by three science educators Internal consistency Cronbach's alpha = .74
MC/SA Conceptual Questions (Items 5, 7, 8, 11, 12)	**Conceptual learning** Quality and depth of mental model & ability to apply information	Content validity – reviewed by three science educators Internal consistency Cronbach's alpha = .61

Analysis of Data

In order to determine whether the experimental groups were equivalent, I analyzed the data from the control measures (the PKQ and the GMRT) using a one-way (3 x 1) analysis of variance (ANOVA). The between-subject variable was relevance instruction. I could not, however, use ANOVA for each of the learning measures (e.g., total number of idea units, number of main ideas, holistic score, etc.), because the data from those assessments did not meet the criteria of being normally distributed. Thus, for the quantitative analysis of the learning outcomes, I used the nonparametric Kruskal-Wallis test (Kruskal & Wallis, 1952) in SPSS.

Qualitative Analysis of the Data

Because traditional assessments are not always sensitive enough to capture differences in student learning, especially with regard to students' mental representations of the text's content, I also carried out a qualitative analysis of the recalls. In their studies, Harp and Mayer (1997, 1998) showed that relevance instructions influence comprehension processes and subsequent recall by activating relevant schema for students. One method of identifying the dominant schema that students used to process the text was to examine the initial sentences of their recalls. If the relevance instructions strongly influenced students' processing of the text, then key terms or phrases, or important ideas from the relevance instruction might appear in students' recalls, particularly at the outset.

The reasoning for this method of analysis comes from Kintsch & van Dijk's (1978) model of text comprehension. The content of a text can be represented as a hierarchy of ideas (or propositions) that reflects the conceptual relationship among those ideas. The top-level ideas—or the ideas that globally capture the content, or the gist, of the text—are called macropropositions (Kintsch & van Dijk, 1978). These macropropositions (or main ideas) are often explicit in the text, but they may also be inferred. In expository writing, authors often place the top-most idea(s) at the beginning of the text (e.g., as the topic or main-idea sentence). Similarly, students who develop a well-structured mental model of a text might also include the top-level macroproposition at the beginning of their recalls, or include macropropositions as organizing ideas within their recall. For example, in this study, students who received the structure-function RI might begin their recalls with an overview statement regarding the structure and function of receptors. Thus, I examined the first two sentences of each student's recall and compared the initial ideas that appeared among the three groups to determine whether the relevance instructions influenced the overarching schema that students used to comprehend the text.

Moreover, if the relevance instructions had the effect of orienting students to the important ideas in the text, then I might expect to see the receptor's role in tasting sweet to be emphasized in students' recalls. Students might include more idea units related to receptors (from paragraphs 2 and 4 of the *Sense of Sweet* text) or discuss the role of the receptor in a more in depth manner. Thus, I compared among the groups the quality of student explanations (e.g., the level of detail) revolving around the core ideas of the mechanism of the receptor.

Examining Groups Based on Reading Skill

In order to answer the research question regarding the relationship of reading ability to the effect of the different types of relevance instructions, I divided the participants into three groups (low-, average-, and high-skilled readers) based on students' total GMRT scores. The high-skilled readers were those who scored above the 66th percentile (n = 17), and the low-skilled readers were those who scored below the 33rd percentile (n = 16). The average-skilled readers were those who scored in between (n = 17). The mean GM test scores and the standard deviations for the two groups were as follows: low-skilled, M = 37.1, SD = 9.3; average-skilled, M = 54.9, SD = 4.2, high-skilled, M = 74.6, SD = 7.1. Since there were not enough participants to carry out a meaningful quantitative comparison, the evidence from the three groups was analyzed qualitatively in order to draw some tentative conclusions about the possible interactions between reading skill and the effect of the relevance instructions.

Specific Ideas that Are Recalled Vis-a-Vis Relevance Instruction and Reading Skill

Although the total number of main ideas and receptor-related ideas was measured from student recalls, it would be useful to determine whether there were any differences in the recall of specific idea units based on the relevance instruction that the students received. For example, would students who received the structure-function RI show stronger recall of ideas 61 through 63 (which described the relationship between the structure and function of receptors most explicitly)? Similarly, were there differences in other specific of main ideas recalled among the different groups? Which ideas tended to be recalled the most—whether important or not? I also wanted to analyze the recall of specific main ideas in relation to the reading skill of the students. Thus, I conducted a content analysis of the recalls, based on the method used by Hidi and Baird (1986), to determine the percentages of specific ideas that were recalled. From the analysis, I could determine whether there was a possible correlation between relevance instruction and the specific types of ideas that were recalled. Likewise, I could examine the possible correlation between students' reading skill and recall of specific ideas.

Correlations between Learning Outcomes, Relevance Instruction, and Reader Factors such as Reading Skill and Prior Knowledge

Because reading skill and prior knowledge are known to be significant factors in the comprehension of science texts, I sought to measure their relative effects by comparing the correlations between these factors and the various learning measures. I obtained the correlations using SPSS.

Chapter 4

RESULTS

Equivalence of Experimental Groups

Descriptive statistics for the prereading measures of reading skill and prior knowledge are presented in Table 4.5. The table shows that there were no significant differences on all of the measures. Thus, although the participants ranged from sixth to eighth grade and were recruited from eight different schools, the groups appeared to be sufficiently equivalent for the purposes of the study. The scores on the vocabulary and comprehension subsets of the GMRT varied widely, with an average score of 62% ± 20% on the vocabulary section and 58% ± 21% on the reading comprehension section. The average total score was 60% ± 18%. According to the GMRT Manual for Scoring and Interpretation, the scores mean that the average student read at the eighth grade level, with the majority of students (within one standard deviation) reading somewhere between the sixth grade to twelfth grade level.

Table 4.5

Mean Scores and Results of ANOVA for Reading Skill (GMRT) and Prior Knowledge (PKQ) Pre-reading Measures

	Experimental groups						Overall (n = 50)		F	Sig.
	Understanding (n = 17)		Explain (n = 17)		Structure-Function (n =16)					
	M	SD	M	SD	M	SD	M	SD		
GMRT vocab (out of 45)	28.6	7.6	26.1	7.5	27.8	10.6	27.5	8.5	0.395	.676
GMRT comprehension (out of 48)	29.1	10.3	24.8	10.3	31.4	9.12	28.4	10.1	1.898	.161
GMRT overall (out of 93)	57.8	17.5	50.9	15.2	59.2	17.9	55.9	16.9	1.161	.322

(continued)

Table 4.5

Mean Scores and Results of ANOVA for Reading Skill (GMRT) and Prior Knowledge (PKQ) Pre-reading Measures (continued)

	Experimental groups									
	Understanding (n = 17)		Explain (n = 17)		Structure-Function (n =16)		Overall (n = 50)		F	Sig.
	M	SD	M	SD	M	SD	M	SD		
PKQ topic (4 pts)	0.93	0.56	0.79	0.54	0.95	0.68	0.89	0.59	0.342	.712
PKQ domain (6 pts)	1.90	1.51	1.76	0.83	1.78	1.45	1.82	1.27	0.053^{*}	.949
PKQ overall (10 pts)	2.82	1.88	2.56	1.23	2.73	1.82	2.70	1.63	0.111	.895

* Because the PKQ domain data did not meet the criteria of homogeneity of variance, Welch's F statistic was used for the ANOVA.

Among the questions that tested students' domain knowledge (Questions 5 – 10), fewer than 20% of students answered correctly the questions related to molecules, receptors, and the vocabulary term *conform* (Questions 5, 8, and 9, respectively). The performance of students on Question 10 ("In science class, you may have heard the phrase 'structure affects function.' What does that mean? Can you provide an example?") seemed to be particularly grade-dependent, with students in the higher grades performing better. Eight of the 10 eighth-grade students received full or partial credit for their answer, whereas six of the 21 sixth-graders and five of the 20 seventh graders received credit for their answers. The relationship between prior knowledge, the influence of grade level, and student performance will be discussed in more depth in the discussion section.

Experimental Results

In this study, I sought to determine how different types of relevance instructions (i.e., a generic RI, an explanation RI, and a higher-level RI focused on key ideas) influenced students' recall and factual and conceptual learning from science text. Students' mean post-reading scores are presented in Tables 4.6 – 4.8, in sequential order of the instruments that were used [the free recall, the short-answer performance questions, and the combined multiple-choice/short-answer test (MC/SA)].

Total Recall and Recall of Main Ideas and Details

Total recall. Students' recall of the text varied widely, ranging from 4% to 48% of the total idea units. In general, recall was moderately low, with a total mean recall of 21% ± 10% across the three groups (Table 4.6, row 1). The structure-function RI group (Group 3) performed best on total recall, recall of main ideas, and the recall of less important details, although the scores for students in the general understanding RI group (Group 1) were close to those of Group 3. The explanation RI group (Group 2) performed more poorly than the other two groups on these measures, although the differences in scores did not reach statistical significance. For total recall, there were no statistically significant differences among the three groups, $H(2) = 4.04$, $p = .133$ (Table 4.6, row 1).

Recall of main ideas and details. Students recalled, on average across the three groups, 30% ± 16% (Table 4.6, row 3) of the main ideas related to receptors (from paragraphs 1, 2, 4, and 5). I hypothesized that the explanation RI might improve students' recall of these main ideas because theoretically the instructions would focus students' attention on the ideas needed to construct a causal situation model of the process of tasting. The results, however, show that Group 2 underperformed relative to the other two groups, and that the difference in scores approached significance, $H(2) = 5.29$, $p = .071$ (Table 4.6, row 3). Interestingly, despite the difference in recall of main ideas, the three groups performed more similarly on recall of less important idea units, $H(2) = 0.82$, $p = .663$ (Table 4.6, row 4).

Holistic Score

For the holistic measure, students, on average across the three groups, scored 2.3 out of 4.5 (Table 4.6, row 5). [For reference, a score of two represented a recall with a rudimentary explanation of tasting sweetness (containing a passing or no reference to the role of receptors), whereas a score of 2.5 indicated a rudimentary explanation with the presence of additional

Table 4.6

Mean Scores and Results of the Kruskal-Wallis Test for Recall

	Group 1 Understanding (n = 17)		Group 2 Explain (n = 17)		Group 3 Structure-Function (n =16)		Overall (n = 50)		KW test statistic	Sig.
	M	SD	M	SD	M	SD	M	SD		
1) Total ideas + inferences recalled (out of 76)	15.9	5.8	13.7	7.2	18.3	8.5	15.9	7.3	4.04	.133
%	20.9	7.6	18.0	9.5	24.1	11.2	20.9	9.6		
2) Main ideas recalled (out of 32)	9.4	3.3	7.8	4.3	10.8	4.1	9.3	4.0	5.65	.059
%	29.4	10.3	24.4	13.4	33.8	12.8	29.1	12.5		
3) Main ideas about receptors (paragraphs 1, 2, 4, 5) (out of 19)	5.9	2.8	4.4	3.1	6.7	3.0	5.6	3.1	5.29	.071
%	31.1	14.7	23.2	16.3	35.3	15.8	29.5	16.3		
4) Less-essential ideas recalled (out of 44)	6.5	3.2	5.9	3.8	7.5	5.6	6.6	4.2	0.82	.663
%	14.8	7.3	13.4	8.6	17.0	12.7	15.0	9.5		
5) Holistic score (out of 4.5)	2.3	1.1	1.9	1.1	2.6	1.1	2.3	1.1	3.76	.153

details.] There was no significant difference in the holistic scores among the three groups, H(2) = 3.76, p = .153, although Group 2 performed more poorly than the other two groups.

Effect of RIs on Learning Prompted Content

The results for the Part 2 short-answer performance questions are presented in Table 4.7. Overall, the three groups demonstrated a low level of learning, particularly for questions B, C, and D. The scores for question B (out of 2 points) were notably low. Moreover, each of the disciplinary-aligned relevance instructions did not lead to improved learning of the prompted ideas compared to the general RI or other treatment group: Question A, H(2) = 2.39, p = .303 and Question B, H(2) = 1.93, p = .381 (Table 4.7, rows 1 and 2). For questions C and D, there was no statistically significant difference among the scores: H(2) = 2.76, p = .251 and H(2) = 4.09, p = .130, respectively (Table 4.7, rows 3 and 4). As with the recall, students in Group 3

Table 4.7

Mean Scores and Results of the Kruskal-Wallis Test for Short-answer Performance Questions

	Understanding (n = 18)		Explain (n = 17)		Structure-Function (n =16)		Overall (n = 51)		KW test statistic	Sig.
	M	SD	M	SD	M	SD	M	SD		
1) Question A (4 pts)	1.7	1.1	1.5	1.3	2.1	1.4	1.8	1.3	2.39	.303
2) Question B (2 pts)	0.35	0.61	0.18	0.53	0.44	0.73	0.32	0.62	1.93	.381
3) Question C (2 pts)	0.65	0.86	0.24	0.63	0.89	0.50	0.79	0.25	2.76	.251
4) Question D (2 pts)	0.65	0.9	0.24	0.66	0.75	1.00	0.54	0.84	4.09	.130

Question A: How are we able to taste sweetness?
Question B: Explain how the structure of sweet receptors is important to how it works.
Question C: What was a recent important discovery about sweet receptors?
Question D: Why does a lemon taste sour and not sweet? Use the word "receptor" in your answer.

scored the highest on all questions and students in Group 2 scored the lowest—although the differences among the three groups did not approach significance.

Students scored poorly on Question B in particular. Students often provided an answer that reaffirmed the importance of the sweet receptor—without explaining how the structure of the receptor affected the function. For example, student 55 wrote: “The structure of receptors are important to how they work because without them, the sense of sweetness can’t be tasted”. Student 12 wrote: “The structure of sweet receptors is important, because otherwise the receptors might taste something different, then it supposed to.” Students’ difficulty with Question B may have stemmed from unfamiliarity with the academic-scientific terms *structure* and *function,* demonstrated by their performance on Question 10 of the PKQ described above

Effect of RIs on the Traditional MC/SA Assessment: Factual and Conceptual Learning

Overall, students were able to answer two-thirds of the MC/SA questions correctly and performed better on the MC/SA test compared to the recall or Part 2 questions. The Kruskal-Wallis tests revealed that there was a significant difference in student performance among the three groups on the factual knowledge questions, H(2) = 7.27, p = .026 (Table 4.8, row 1); the questions for conceptual understanding, H(2) = 6.22, p = .045 (Table 4.8, row 2); and the overall score, H(2) = 7.870, p = .020 (Table 4.8, row 4). For the factual questions, post-hoc analysis in SPSS revealed that the significant difference existed between Groups 1 and 2 (U = 12.15, adj. significance p = .036, effect size r = .43) with Group 1 students scoring higher than those in Group 2. For the conceptual questions, the significant difference existed between Groups 2 and 3 (U = 12.58, p = .038, r = .43), with Group 3 performing better than Group 2. For the total MC/SA score, post-hoc analysis revealed that the significant difference existed between Groups 2 and 3 (U = 13.35, p = .025, r = .46), with Group 3 outperforming Group 2.

Table 4.8

Mean Scores and Results of the Kruskal-Wallis Test for Performance on the Multiple-choice/Short-answer Assessment

	Understanding (n = 17)		Explain (n = 17)		Structure-Function (n =16)		Overall (n = 50)		KW test statistic	Sig.
	M	SD	M	SD	M	SD	M	SD		
1) Factual questions (out of 5)	4.2	1.1	2.8	1.5	3.8	1.7	3.6	1.5	7.27	.026
2) Conceptual questions (out of 5)	3.0	1.4	2.4	1.2	3.5	1.2	3.0	1.3	6.22	.045
3) Receptor Conceptual questions (out of 3)	2.1	1.1	1.7	0.9	2.4	0.8	2.0	1.0	5.41	.067
4) Total score (out of 10)	7.2	2.2	5.3	2.3	7.3	2.7	6.6	2.6	7.87	.020
Total score (%)	72	22	53	23	73	27	66	26		

Content analysis of MC/SA questions. A content analysis of the MC/SA questions provided insight into the effect of the different RIs (see Figures 4.2 and 4.3 below). For the factual questions, Group 1 students did well on Questions 2 and 3, and to some degree Question 6. Surprisingly, Group 2 students performed poorly on question 2 (Which step is *not* a part of the process of tasting sweet?), a question I would have expected them to do well on. One reason may be that the low-skilled readers were particularly challenged by the negative construction of that question (which seemed to be the case for Group 3—three of the four low-skilled readers answered it incorrectly). However, in Group 2, it was both low- *and* average-skilled readers who got the problem incorrect.

For the conceptual questions, Group 3 students scored well on Questions 5 and 8 in particular—two of the questions that related to the receptor mechanism. Question 7 was

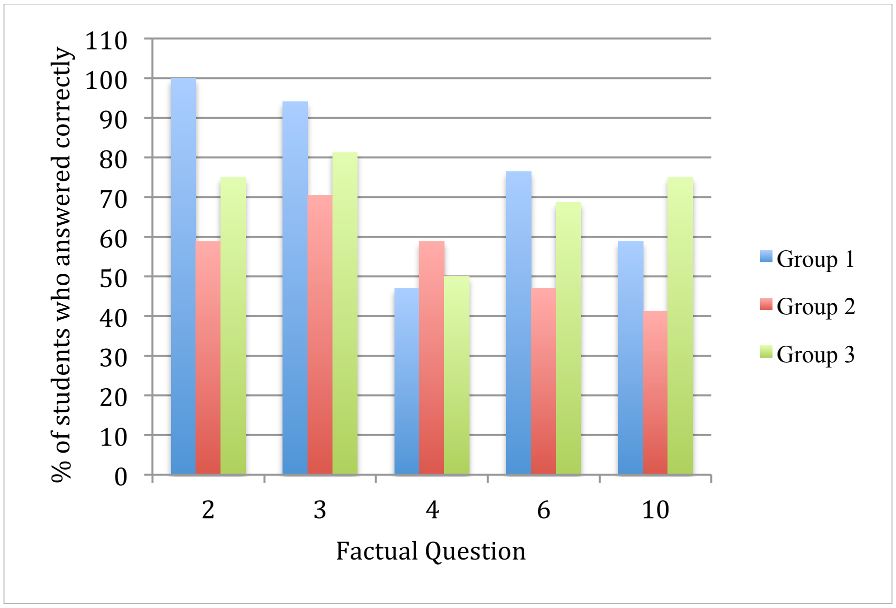


Figure 4.2. Performance of Groups 1, 2, and 3 on the Factual MC/SA Questions

2. Which step is not a part of the process of how a sugar molecule is tasted as sweet?
3. Where are taste receptors located?
4. What are the structures that "receive and attach to specific substances"?
6. What happens to taste molecules in tomatoes as they become more ripe?
10. Describe the taste of umami.

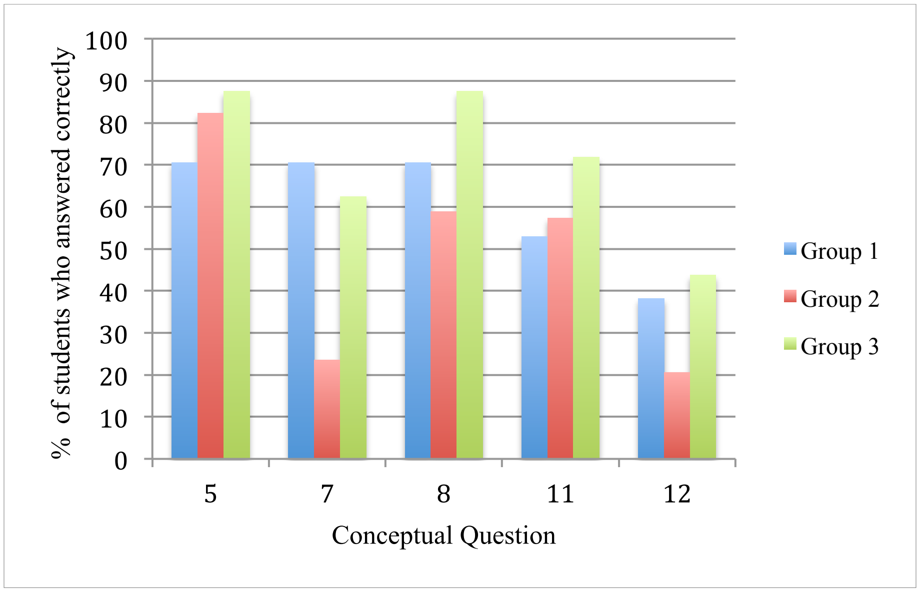


Figure 4.3. Performance of Groups 1, 2, and 3 on the Conceptual MC/SA Questions

5. Why doesn't salt taste sweet?
7. What would happen if the shape of all the sweet receptors in your tongue were somehow changed?
8. Which of the following is the best explanation of why we are able to taste the sourness of a lemon?
11. List the kind of taste molecules you would find in pizza.
12. Explain why cats cannot taste sweetness, even if they eat something sweet.

interesting in that Group 2 students again performed notably worse compared to the other two groups. Because the answer choices were lengthy phrases, the reason may have been in part due to lower reading ability of the students in Group 2, but a number of average-skilled readers also answered that question incorrectly. The most commonly selected detractors were that "the ability to taste sweetness would not change because the shape of the sweet molecule has not changed," and that "the ability to taste sweetness would be reduced because the sugar molecules would be free to attach to all the other receptors." It seems that Group 2 students had a tenuous grasp of the mechanism of the receptors. One explanation is that students did not know how to interpret the relevance instruction. That is, they knew they had to explain sweetness, but without enough background knowledge, students may not have had well-formed criteria to determine what content was actually relevant, and focused on the general process of tasting rather than on the receptors. Also, the continued need to assess what was relevant while reading may have interfered with their ability to form a coherent mental model.

Summary of Quantitative Findings

Overall, students did learn from the text to varying degrees measured by the different instruments: on average, students remembered 21% ± 10% of the total idea units and 29% ± 13% of the important idea units in recall (see Table 4.6). They demonstrated a low-level of understanding on the Part 2 performance questions, but scored about 66% ± 26% on the traditional MC/SA test; and had an average holistic score of 2.3 ± 1.1—a score that indicates that students, on average, provided an elementary explanation of tasting sweetness.

With regard to Research Question 1, the data shows that students who received the generic instruction for best understanding (Group 1) performed better on the MC/SA measure of factual learning—although not on the measures of factual learning in the recall; whereas the students who received the instruction that focused on the key concepts (structure-function RI-Group 3) performed better on the MC/SA measure of conceptual learning (at a significant level), as well as on the conceptual measures of the recall at a level approaching significance. In general, Group 2 (who received the explanation RI) performed poorly relative to Group 1 and 3 on all the measures, a finding that will be discussed in more detail in the Discussion section.

Qualitative Analysis of the Data

The MC/SA assessment revealed some statistically significant differences in the learning outcomes among the three RI groups. However, because only five questions comprised each of the factual and conceptual components, I conducted a more fine-grained, qualitative analysis of the recall data in order to more fully assess the effect of the relevance instructions.

Effect of RIs on initial macropropositions and processing. I examined the initial two sentences of students' recalls to determine which ideas held most prominence in students' conceptions of the text—and to see whether they included the overarching idea of the text, which was to explain how we taste sweetness. Most students included specific, concrete facts or details in the first two sentences. For example, student 50 wrote, "I learned that we have 10,000 taste buds. Cats don't like sweet foods." The most common ideas that appeared were taste buds (72%), food molecules (38%), 10,000 *taste buds* (32%), umami (30%), *food is* broken down (28%), sweetness (26%), and sourness (24%). Of the 50 students, 15 began their recall with a clear explanatory overview statement or topic sentence that reflected the top-level macroproposition (i.e., how we taste sweetness). For example, student 36 began their recall with "I learned on how we can taste sweetness. We can taste sweetness when we eat something sweet and molecules float on your taste buds...."

Most of the 15 overview statements came from recall protocols of average- and high-skilled readers (five and eight statements, respectively). When the statements were sorted by treatment group (there happened to be five from each group), some interesting observations could be made. For example, four of the five overview statements for Group 2 closely reflected the relevance instruction they had received (i.e., “you should be able to explain *how we are able to taste sweetness*”). The five statements from Group 2 are listed below (emphasis added). [The number within the parentheses identifies the student and the letter represents their reading skill: L (low), A (average), and H (high). Spelling errors for common words and distracting grammar errors were corrected in student recalls. Otherwise, student recalls appear as written.]

- “I learned on **how we can taste sweetness**. We can taste sweetness when we eat something sweet…” (36-L)
- “Sweetness.” After describing the process, the concluding sentence of the paragraph was “That is **how we identify sweetness.** (7-A)
- I learned that **how we are able to taste sweetness** is by when we chew, our saliva… (41-A)
- “From this article, I learned how we taste things.” (Then provides a brief and accurate description of the process.) (62-H)
- “What I learned about is **how we taste sweetness**, for example a banana. Our saliva breaks down fruit into separate molecules.” (Proceeds to describe the process in detail.) (30-H)

In each of these cases, the student went on to describe the process of tasting sweet, largely using ideas from paragraph 2 of the text.

In contrast, the overview statements from Group 1 (who received the general relevance instruction) were more varied, without a unified phrase as for the Group 2 statements. The Group 1 students generated different yet valid macropropositions to capture the content of the text. It is notable that none of the students focused solely on how we taste sweetness, but inserted other closely related topics or terms, such as tasting in general or taste buds. All five initial overview statements from Group 1 are listed below:

- “We can identify a sweet taste all from our tongue.” (Goes on to describe the process.) (29-A)
- “From this article I learned about how we as human along with some animals sense TASTE!” (55-A)
- “What I learned was that there is a lot of structures that contribute to the process of tasting sweet. For example, in the text it included ‘taste buds’ and ‘receptors’…” (13-H)
- “This article is about how taste buds taste a sweet flavor from foods. It includes facts such as the tongue has 10,000 taste buds….” (35-H)
- “This article is about how we taste different types of qualities in food, which are sweetness, sourness, saltiness, bitterness, and umami.” (16-H)

Students in Group 3 received the instruction “explain how the structure of sweet receptors affect the way they work.” Aside from the recall of student 15, the overview sentences did not reflect the relevance instruction as they did with Group 2. The five overview statements from Group 3 appear below:

- “What I've learned from this article is sweetness. I learned that you have 10,000 taste buds and each of them contain 5 receptors: sweet, sour, ….” (33-L)

- "I learned many great things in this article such as taste buds and different types of tastes, and molecules." (48-A)
- "There are many things I learned in this article. One thing I learned is how you know that what you are tasting is sweet. First your saliva breaks down…" (34-H)
- "Sweetness. It's in almost everything… But what if you just stopped tasting it. It's not a curse, it's just that something stopped working in your taste buds." (Goes on to describe the process, and finishes with "In conclusion, this is how we taste sweetness.") (51-H)
- "The structure on how taste buds are built is very important to how they work." (Proceeds to explain how the taste buds (sic) have two proteins, which are part of the structure, but if one is missing, then we can't taste sweetness.) (15-H)

If the relevance instruction influenced the macroprocessing of the text as it seemed to with some students in Group 2, why did the overview statements from Group 3 not reflect the structure-function relevance instruction as clearly (aside from student 15)? One explanation is that skilled readers, consciously or through more automatic processes, seek to construct a coherent mental representation of the text. Although the receptor and related statements about its structure and function are key ideas, skilled readers identified a more overarching proposition under which those ideas could be subsumed. In this case, the main topic—an explanation of how we taste sweetness—was clearly signaled at the outset of this coherent text. Also, students may have been less motivated to adopt the relevance instruction if it was not readily comprehensible.

These observations indicate the potential of relevance instructions to influence the comprehension processes of some students (mostly seen for Group 2). Their overall effectiveness, however, is not so clear-cut, since a number of overview statements from Groups 1 and 3 focused on sweetness without necessarily using the explicit phrase "how we are able to taste sweetness."

The effect of RIs in targeting instructionally important content. A closer examination of how receptors was discussed in student recalls might also reveal which relevance instruction(s) was more effective in helping students to grasp the role of receptors in tasting and the relationship between their structure and function. I reviewed all the recalls that included the term *receptor*. On the whole, 25 students (50% of the sample population) included the term in their recalls.

There were some interesting qualitative differences in how students in the three groups used the term receptor or described its role. In Group 1, the description of the receptor varied considerably. Students described how the receptor was involved in the process of tasting, or mentioned that it had a role in detecting tastes. Below, I have included *all* appearances of the term receptor from Group 1 recalls. The critical detail of the shape of the receptor fitting the shape of the food molecule was sometimes mentioned, as seen in the bold phrases.

- "…As the molecule is broken down it sets to be a receptor. The receptor sets off a signal to your brain which tells the different senses…." (46-L)
- "…And one molecule goes onto 1 taste bud and that molecule attaches to the sweet receptor…If it wasn't for our receptors on our taste buds we wouldn't be able to taste sweetness…." (29-A)
- "…The receptor in taste bud send message to brain telling it is sweet…" (2-A)
- "On our tongues we have 10,000 taste buds or receptors. Each [receptor] is attracted to a different taste." (55-A)

- "…For example in the text it included "taste buds" and "receptors" which take an important role in tasting something….Lastly, **the molecules are specifically matched into the receptor based on their shape**…." (13-H)
- "[Taste buds] have receptors for sweet, sour, bitter, salty, and unami flavors…. The taste receptor determines which of the 5 flavors does it taste like…." (35-H)
- "…I also learned that our teeth break down food into molecules that drift into sweet receptors. I learned that **only one specific molecule can go into its receptor**…." (40-H)
- "…Our mouth has about 10,000 taste buds, which have their own open onion shaped receptors. These receptors taste the qualities in food. But first, when we eat, our saliva breaks down the food into **separate molecules which will shape up to the receptors size."** (16-H) [the reference to receptor's size is unclear]

In Group 2, the receptor was more frequently mentioned in the context of the *process* of tasting, which aligns with the relevance instruction that asked students to explain how we are able to taste sweetness. Below, I have included all appearances of the term receptor from Group 2 recalls, with phrases that describe the mechanism of receptors and taste molecules fitting each other placed in bold. Students often used ideas from paragraph 2 of the reading text (the paragraph that described the sequence of tasting sweet) in their recall of receptors, and a number of students used the key and lock analogy (from paragraph 2) to describe the fitting of the receptor and the molecule.

- "…On the top [of the taste bud] is a receptor that separates the taste of food such as sweet, salty…**When you eat your food it separates it into different receptors based**

on the taste. The different tastes are like a key to a door which means a new taste goes in a receptor.” (56-L)

- “…Each molecule has different receptors. **Sugar will fit into the sweet receptors….”** (50-L)
- “…Then [the taste] get attached with certain receptor. The **receptors are certain things that attach those substances to fit in like a key & lock….The receptors have/always interlock with the right taste.”** (7-A)
- “…taste buds… have receptors which signal sweet, sour, bitter or umami, which signals our taste buds what kinds of taste the food has.” (41-A)
- “…You can taste food by taste buds that have little receptors that send signals to the brain and **conforms to the particle [in?] the person’s meal.**” (59-A)
- “These [food] **molecules then fit into different receptors on our tongues.** There are individual receptors for each taste. In the end, the receptors send signal to the brain and tell it the taste.” (62-H)
- “Inside the taste buds are different receptors…**The [taste] molecule has to fit into the right receptor, like a key and a door.** When the molecule fits it sends signals to your brain.**”** (30-H)

Turning to Group 3, I found their recalls displayed some variety in how receptors were characterized. However, more of the Group 3 recalls described the receptors substantively, making more reference to the *shape* of receptor or food molecules and providing more details of how they fit together, as shown in the following list of all the Group 3 excerpts containing the term receptor.

- "…I learned that you have 10,000 taste buds and each of them contain 5 receptors: sweet, sour, …" (33-L)
- "…Inside your taste buds are taste cells, which contain different types of receptors. These receptors are all different depending on the taste like sweet, sour, bitter, salty…Each taste has a different shape in order for the taste to taste either sweet, salty, bitter, sour, or umami." (28-A)
- "…I also learned that inside these buds there are receptors. The receptors distinguish sweet, sour, bitter, etc. tastes. …The receptors look like onions with an opening at the top under a microscope." (31-A)
- "…In the taste bud, there are many receptors. Each receptor "detects" a kind of taste. …Each of the [taste] molecules have a different shape that indicates a taste. The **receptor has a space in them like a mold, so only the molecules with the correct shape can fit into them."** (12-H)
- "…If what your are eating is sweet, it will fit into your sweet receptor then when it goes in, it sends a signal to your brain… **Each receptor for the different tastes are shaped different, so depending on which receptor the molecule fits into,** you can have your brain tell what type of taste the food is." (34-H)
- "…and each bud has 5 receptors:… [W]hen something sweet touches your taste bud, **it will conform to the sweet shape receptor and signal it to our brain. Each receptor has a different shape."** (60-H)
- **"Food molecules fit into your tongue receptors like a key in a lock**….Your saliva breaks down the food and then the food molecules land on your receptors…Receptors are a main part of the tasting process." (8-H)

- "…Also taste buds have taste cells where the taste cells have receptors. **Receptors detect the taste and the taste buds from a shape to tell your brain that something is sweet…."** (39-H)
- "[Taste buds] are onion-shaped bumps on the tongue that contain different receptors: sweet, salty…**Different molecules fit into different receptor depending on what the food is**…. (54-H)
- "We can identify different tastes due to receptors in our taste buds. These help us to taste sweet, sour, …" (1-H)

Summary of Qualitative Observations

This qualitative analysis of the recalls suggests the potential of science-aligned relevance instructions (Groups 2 and 3) to direct students' attention to instructionally important ideas. The Group 3 RI (structure - function) seemed most effective among the three in facilitating learning of important concepts—as seen in the richer descriptions and explanations of the mechanism of the receptor. Few students recalled ideas from paragraph 4, which provided a more in-depth explanation of receptors, including information about the structure of receptors (idea unit 61 - "receptors have their own shape"). However, the three students who did recall idea unit 61 (and explained the receptor mechanism in depth) were all in Group 3. They were also all high-skilled readers. Thus, more research is required to determine whether: 1) there is an interactive effect between relevance instructions and reading skill, or 2) the attention to key ideas is more a function of the reading level of students, rather than the relevance instruction provided.

Relevance Instructions and Reading Skill

Regarding reading level, I sought to examine whether there was a differential effect of the relevance instruction for lower- and higher-skilled readers. A tentative qualitative analysis of the data suggests that higher-skilled readers benefit more from and make better use of relevance instructions than lower-skilled readers. Evidence for this comes mostly from Groups 2 and 3, for which it was easier to identify “successful execution” of the relevance instruction.

What does baseline “best understanding” look like (from Group 1)? In order to draw more meaningful conclusions about the effect of the science-aligned relevance instructions for different skilled readers, it was helpful to characterize what “Best Understanding” recalls from Group 1 look like, particularly focusing on the coherence of their explanations of sweetness, and the inclusion of the mechanism of the receptor. The recalls of Group 1 were quite varied, likely due to the general nature of the relevance instruction. Low-skilled and average-skilled readers tended to describe tasting the five tastes in general, rather than on sweetness specifically. For example:

- I learned that you have a taste bud called ummie and it is for tasting something that is savory or good. I learned that your saliva breaks down your food into molecules. I learned that you have cells called taste cells and they send the message that your taste bud is tasting sweet, sour, bitter, and ummie. (21-L)
- From this article I learned about how we as humans along with some animals sense TASTE! On our tongues we have 10,000 taste buds or receptors. Each one is attracted to a different taste. Some include, sweet, sour, bitter, or umani. Once we start to chew the food, our saliva will break up the food’s molecule… Recently studies show that SOME animals can sense all taste. Unlike cats who don’t have a sweetness sense so the are not interested in the wonderful taste of SWEET! (55-A)

Some recalls discussed sweetness more directly, although sweetness was only briefly referenced. For example:

> I learned there are about 10,000 taste buds on your tongue. I found out that under a microscope, a taste bud look like little onions with an open top. I think that learning about the taste buds sending signals to your brain is interesting. When you taste something sweet, your tongue sends signals to your brain and saying how it tastes. (32-A)

The three examples provided above also demonstrate how students tended to organize their recalls around familiar ideas such as tasting, taste buds, or the five tastes, rather than on the process of tasting sweet.

There were two recalls that stood out among Group 1 average-skilled readers, showing that a reading score is not a perfect indicator of true comprehension ability. Students 29 and 6 had recalls that were relatively lengthy and coherent, resembling those of higher-skilled students (see below). Student 6, furthermore, provided clear and cogent answers for all the short-answer questions and received full credit for all of them. Student 29 also did relatively well on the short-answer questions compared to the other average-skilled readers.

- We can identify a sweet taste all from our tongue. Our tongue has 10,000 taste buds on them and when you eat a ripe banana your saliva breaks the food down into small molecules and one molecule goes onto 1 taste bud and that molecule attaches to the sweet receptor. Then it sends a signal to your brain that something sweet has entered your mouth. You can detect sweet, sour,… Dogs have T1RI and T1RII so that can detect these things. But cats on have T2RI so that have no taste for sweetness. If it wasn’t for our receptors on our taste buds we wouldn't be able to taste sweetness. If you look at your taste buds under a microscope your taste bud have a small opening so the molecule can go on the receptor. (29-A)

- When food enters the mouth saliva breaks down the food into separate molecules which then fall into your taste buds containing taste cells. There are 10,000 different taste buds. The molecules and the taste buds act as a key in a lock, the molecule fits into its matching taste bud and it then sends a message to your brain saying there is something sweet, sour, bitter, etc. on your tongue.
  Part 2, question A: Saliva breaks down food into separate molecules and it falls into the taste buds. The molecules fits into its matching receptor and then send a message to your brain saying there is something sweet on your tongue.
  B: Receptors are like the keyhole and the molecules are the key. There are different receptors for different kinds of foods like sour, sweet, etc. The food molecules fit into the receptor for you to know if its sweet or not.
  C: That there are two substances that you need to taste sweetness (you need both). A cat only has one so it doesn't mind for sweet foods.
  D: It taste sour because the sour molecule only fits into the sour receptor, it can't go into a sweet receptor. (6-A)

Thus, although the recalls of low- and average-skilled readers tended to focus on tasting in general, there were instances of average-skilled readers who clearly comprehended the passage and focused on sweetness (e.g., student 29) or who understood the receptor mechanism (e.g., student 6). Likewise, among high-skilled readers in Group 1, there were those who clearly grasped the main ideas of the passage (e.g., students 13 and 35 who wrote about sweetness in an overview sentence and then provided a coherent explanation of the topic), and others who referred to sweetness to varying degrees.

Effectiveness of RIs for higher-skilled readers. When examining the recalls of high- versus low-skilled students, I found the impact of the relevance instructions to be more defined for high-skilled readers in Groups 2 and 3. Group 2 only had two high-skilled readers (students 30 and 62). Student 30's recall began with "What I learned about is how we taste sweetness, for example a banana…." The remainder of his or her recall presents a clear explanation of the content of the text. This student, moreover, provided full answers for Questions A, B, and D that demonstrated complete and accurate understanding of process of tasting sweetness and the complementary mechanism of the receptor. Student 62's recall elaborated on the general process of tasting ("From this article, I learned how we taste things….") without focusing specifically on sweetness. However, their understanding was fully revealed in Part 2, Question A: "We are able to taste sweetness by molecules broken down by saliva fitting into sweetness receptors. The sweetness receptors then signal the brain to tell it the food is sweet."

Despite this evidence, I can only make a very tentative suggestion that both of the Group 2 high-skilled students were influenced by the explanation RI. Aside from there being only two individuals, the other reason is that a few of the Group 1 high-skilled students also focused directly on the topic of sweetness in their recalls (e.g., students 13 and 35). These students from Group 1 also introduced sweetness in an initial overview sentence, albeit their overview sentences did not mirror the wording of the relevance instruction in the same way as for student 30. For example, Student 13 stated: "What I learned from this article was that there is a lot of structures that contribute to the process of tasting something sweet….”; and Student 35 wrote: “The article was about how taste buds taste a sweet flavor from foods.…”).

For Group 3, there were more indications that the relevance instructions had an impact for the high-skilled readers. Among the nine high-skilled readers, seven students referred to receptors. As previously shown in the section on “The Effect of RIs in targeting instructionally important content,” their description of the role of the receptors tended to be richer and focused on the mechanism of the receptor fitting the molecule and its role in distinguishing tastes (see page 73). High-level students from Group 1 also mentioned receptors in their recalls (4 of 6 students), but their description of receptors was more limited (see page 71).

The expanded understanding of the receptor for Group 3 students was also demonstrated in their answers for Part 2 Questions A, B, and D. For Question A, a score of 4 reflected a complete understanding of the role of the receptor in tasting sweetness, including the complementary mechanism. Six out of nine students received a score of 3 or 4 for Question A, whereas in Group 1, none of the higher-level students (n = 6) received a 4 and one student received a 3. [I should note that there was one average-skilled reader who received a 4 (student 6) and another who received a 3 (student 29).] Compared to the Group 1 higher-level students, the Group 3 students also displayed better understanding of the role of the receptor for Question D, which asked them to explain why a lemon tastes sour. A score of 2 represented full understanding of the role of the receptor. Again, six of nine Group 3 students received a score of 2, whereas only one of six Group 1 students received a score of 2 and two students received a score of 1. Although this difference in performance is not statistically significant, the data suggests a potentially significant finding if a larger study were conducted. If anything, the data for high-skilled readers suggests their greater potential to be influenced by relevance instructions.

In addition to influencing student learning, there was also evidence that the RI affected high-level students' strategic processing of the text. For student 60, the instructions had a directly observable effect. He or she underlined all the sentences that contained the word receptor in his or her text. For student 15, the instructions had a narrowing effect to the detriment of overall understanding. The initial sentence of the student's recall (provided below) seems to directly reflect the relevance instruction (even though he or she substituted "taste buds" for "receptors"), but the remainder of the recall shows that the student focused on answering the question in a limited way, without taking into account the full text.

> The structure on how taste buds are built is very important to how they work. For example taste buds have 2 proteins called T1R2 and T1R3, but if one is missing it can't taste sweetness. This shows that the structure on how taste buds are built is very important to how they work because the fact that it has 2 proteins is a part of it's structure, so the structure is important because if they had different type of structure we couldn't taste sweetness. (15-H)

Effectiveness of RIs for lower-skilled readers. It was more difficult to draw conclusions about how the relevance instructions affected the low-skilled readers in Groups 2 (n = 8) and 3 (n = 4)—largely because it was difficult to identify whether a student had been influenced by a particular relevance instruction based on their recalls. For example, of the eight low-skilled readers in Group 2, three students made some reference to sweetness, but that could have been the result of basic comprehension of the text, especially as there were low-skilled readers in Group 1 who also referred to sweetness in their recalls. Similarly, it was difficult to tell whether low-skilled readers in Group 3 were influenced by the structure-function RI since some low-skilled students from Groups 1 and 2 also referred to the role of receptors in their recalls.

Overall, the low-skilled readers showed little explicit evidence that the relevance instruction affected their processing of the text. The one exception was student 36 in Group 2 whose recall began with an overview sentence, “I learned on how we can taste sweetness”.

> I learned on how we can taste sweetness. We can taste sweetness when we eat something sweet and molecules float on your taste buds. There are a few tastes sour, sweet, bitter, and 1 that was discovered by a person in Japan. It’s called umami. When you eat a tomato there is some sweet more sour and even more umami. When you taste sweet, the molecules brake up to your taste buds. If you weren’t able to taste any of those it wouldn’t taste like what it actually is. (36-L)

This recall is a good example of how a low-skilled reader adopted the instruction, but had difficulty executing it. He or she included the initial step in tasting sweetness (molecules floating on taste buds), but did not recall the subsequent (more unfamiliar and abstract) details of the process. The remaining five low-skilled readers in Group 2 seemed *not* to be influenced by the instructions, as they made no reference to sweetness at all, but focused on concrete facts or tasting in general. For example:

> What I learned from the text is that are 4 tastes for your taste buds and something that Japanese people discovered called umami where the food that you taste are yummy. I also learned that if we lose our taste buds we can’t taste the foods that are sweet, sour, bitter, salty, and yummy. (44-L)

Effectiveness of RIs for average-skilled readers. I found more indications that average-skilled readers compared to the low-skilled readers may have adopted their specific relevance instruction, although the benefit to learning was not as clear as with the higher-skilled readers. Among Group 2 average-skilled readers (n = 7), two students (7 and 41) had recalls with an overview sentence that reflected the relevance instruction, and had recalls that presented a coherent explanation of tasting sweetness. Another student (17) also began their recall with a general statement about the topic of sweetness, but the remainder of the recall and answers to short-answer questions did not reflect an understanding of the topic. One student does not appear to have been influenced by the explanation RI at all (discussed umami, taste buds and receptors in the context of tasting), and the remaining three students made some mention of sweetness. For example:

> In the passage I learned that there are 5 senses of taste and they include sweet, bitter, sour, salty, and umami (savory). I also learned that a chemical named T1R2 is released to signal the brain that what you are tasting is sweet and that cats don't have this so they have no interest in what we consider sweet. (9-A)

Although some students referred to sweetness it is not clear that they were influenced by the relevance instruction, especially as there were some average-skilled students in Group 1 who also discussed sweetness, for example:

> I learned there are about 10,000 taste buds on your tongue. I found out that under a microscope, a taste bud look like little onions with an open top. I think that learning about the taste buds sending signals to your brain is interesting. When you taste something sweet, your tongue sends signals to your brain and saying how it tastes. (32-A)

Because there were so few average-skilled students in Group 3 (n = 3), it was difficult to make any generalizations about the effect of the RI that targeted core ideas. At least two of the students (28 and 31) seem to have been influenced by the instruction in a way that also affected how they described the process of tasting sweet. Whereas two of the average-skilled readers in Group 1 made a brief reference to the receptor:

- "The receptor in taste bud send message to brain telling it is sweet…" (2-A)
- "…that molecule attaches to the sweet receptor. Then it sends a signal to your brain…" (29-A)

students 28 and 31 in Group 3 described the receptors more in depth (emphasis added):

- I learned that when you chew a type of food the saliva in your mouth breaks it down into little molecules. The molecules will float into your taste buds. Inside your taste buds are taste cells, which *contain different types of receptors. These receptors are all different depending on the taste* like sweet, sour, bitter, salty, and a savory or yummy taste called umami. *Each taste has a different shape* in order for the taste to taste either sweet, salty, bitter, sour, or umami. (28-A)
- From this article I learned that everyone's tongue has about 10,000 taste buds. I also learned that *inside these buds there are receptors. The receptors distinguish sweet, sour, bitter, etc. tastes*. It also introduces umami in which is a savory taste. The *receptors look like onions* with an opening at the top under a microscope. (31-A)

Although these Group 3 average-skilled readers seem to have been influenced by the specific explanation relevance instruction, it was not in such a definitive way as to make a clear difference in their performance on the various assessments (particularly on the Part 2 short-answer questions).

Summary of the Use of RIs with Students of Different Reading Abilities

Overall, the review of student recalls and answers on the Part 2 questions suggests that higher-skilled readers benefit most from relevance instructions. This effect was most clearly seen with the structure-function instruction (Group 3), as the high-level students demonstrated more focus on and more detailed descriptions of the core ideas related to the receptor. The high-skilled readers in Group 2 also clearly utilized the relevance instruction, although one cannot draw a definitive conclusion with so few samples. The different relevance instructions appeared to have a much weaker or no readily distinguishable influence on lower-skilled readers, at least measured by their ability to express themselves on the written recall. Finally, some of the average readers in Groups 2 and 3 showed some indications of adopting the relevance instruction, although they were less effective than the high-level readers in executing the instructions.

Differences in Recall of Specific Main Ideas

In addition to providing insight on the function and effect of relevance instructions, the content analysis of student recalls can also help add to our knowledge of what middle-school students *do* remember, in general, from reading a science text; how well main ideas stick; and how relevance instructions affect the learning of particular main ideas. Although this study uses one text, some of the results confirm (or offer new data) about what students pay attention to when reading, particularly in relation to factors such as prior knowledge; interest and seductive details; and student knowledge/beliefs about what is important when reading scientific texts.

I determined the percentage of student recall for each of the main idea units (Table 4.9). The results show that students had low recall of important ideas, even when the important ideas were signaled by the relevance instruction. From Table 4.6 (rows 1 and 2) we saw that, overall, students recalled on average 29% of the main ideas in the text and 21% of the total ideas in the text.

More significant to the use of texts in science instruction was that students had difficulty grasping the important ideas that would likely be the instructional objective of having students read. One of the primary purposes of the text was to describe and explain the role of the receptor in tasting sweet. Yet for each paragraph, the idea units related to the receptor were recalled the least. For example, in paragraph 2, a number of the key steps in the process of tasting sweet (idea units 11, 13, 31, and 33) were recalled by 32 – 50% of students. These idea units described how food molecules were broken down and floated into taste buds, as well as how a signal was sent to the brain by the receptors. However, the steps in the sequence that discussed the receptors (idea units 28, 29, 30) were remembered more poorly (25% of students or fewer). I note, however, that the specific terms *receptors* and *molecules* were commonly recalled (51% and 62%, respectively). In paragraph 3, the information that was not directly relevant to the explanation of tasting sweet, but which was familiar to students, was recalled well—particularly the five tastes. Interestingly, new, technical details such as *umami* and *10,000 [taste buds]* had a high percentage of recall (75% and 46% respectively). In contrast, the important ideas of paragraph 3 such as "each taste bud has receptors for all five tastes" and "foods spark reactions in more than one receptor" (idea units 36 and 47) were rarely recalled (6% and 7% respectively). Likewise, the propositions in paragraph 4 were critical to the understanding of how receptors were able to distinguish various tastes. However, the ideas from this paragraph were recalled the least; fewer than five students recalled idea units 61, 62, or 63, which provided an explicit explanation of why certain tastes could only fit in certain receptors.

Lastly, in the key ideas of paragraph 5 (idea units 67, 72, and 73—that sweet receptors consist of two parts and that if either part is missing, one can't taste sweetness) were not well recalled (8%, 22%, and 18%, respectively). In contrast, the fact that cats aren't interested in sweet foods because they are missing part of the receptor was more readily remembered (35%). The technical terms T1R2 and T1R3 were also remembered more frequently (32% and 27%) than the essential ideas in this paragraph.

One of my research questions was: which instruction seemed to facilitate the learning of main idea units? When considered in terms of total instances of recall of main ideas (Table 4.10, first row), Groups 1 and 3 outperformed Group 2 by a small margin (8% and 8% versus 6%). There were differences in which specific main ideas were emphasized by different groups. For example, Group 1 had the highest recall of the steps involved in the process of tasting (idea units 11, 13, 31, and 33); whereas, Group 3 students more frequently mentioned idea units related to the receptor (idea units 21, 36, 61, 62, 63, and 77).

Beyond the influence of relevance instructions, reading skill seemed to play a role in students' learning of main ideas. The differences in recall of main ideas among low-, average-, and high-level readers was 4%, 8%, and 11% (Table 4.10, first row). The average- and high-skilled readers recalled steps related to the process of tasting, but the high-skilled readers tended to note the important step of the food molecule fitting its matching receptor (idea unit 29) and were more likely to remember ideas from paragraphs 4 and 5.

Table 4.9

Percentage of Student Recall of Main Idea Units

Idea unit [Paragraph that the idea unit appears in]	Total # of students who recalled the idea unit (%)	# of Group 1 students (%)	# of Group 2 students (%)	# of Group 3 students (%)	# of low-skilled readers (%)	# of average-skilled readers (%)	# of high-skilled readers (%)
4. How do we sense sweetness? [1]	14 (28%)	4 (24%)	5 (29%)	5 (31%)	3 (19%)	4 (24%)	7 (41%)
5. A lot happens [on tongue when we taste something sweet] [2]	0	0	0	0	0	0	0
11. Food is broken down [2]	25 (50%)	11 (65%)	6 (35%)	8 (50%)	4 (25%)	9 (53%)	12 (71%)
13. Floats into [2]	19 (38%)	7 (41%)	6 (35%)	6 (38%)	1 (6%)	9 (53%)	9 (53%)
14. Taste bud [2]	46 (92%)	16 (94%)	14 (82%)	16 (100%)	15 (94%)	16 (94%)	15 (88%)
29. [food molecule] fits a matching receptor [2]	12.5* (25%)	2.5 (15%)	5 (29%)	5 (31%)	2 (13%)	3 (18%)	7.5 (44%)
31. Sends a signal [2]	22 (44%)	10 (59%)	5 (29%)	7 (44%)	5 (31%)	9 (53%)	8 (47%)
33. Tells you something is sweet [2]	16 (32%)	8 (47%)	3 (18%)	5 (31%)	3 (19%)	7 (41%)	6 (35%)
36. Each taste bud has receptors for all five tastes [3]	3 (6%)	0 (0%)	1 (6%)	2 (13%)	1 (6%)	1 (6%)	1 (6%)
47. Foods spark reactions in more than 1 kind of receptor [3]	3.5 (7%)	1 (6%)	2 (12%)	0.5 (3%)	1 (6%)	0 (0%)	2.5 (15%)
59. All sugars fit in sweet receptors [4]	1.5 (3%)	0.5 (3%)	1 (6%)	0 (0%)	1 (6%)	0 (0%)	0.5 (3%)
60. But not in sour or bitter receptors [4]	2.5 (5%)	1.5 (9%)	1 (6%)	0 (0%)	0 (0%)	1 (6%)	1.5 (9%)

(continued)

Table 4.9

Percentage of Student Recall of Main Idea Units (continued)

Idea unit [Paragraph that the idea unit appears in]	Total # of students who recalled the idea unit (%)	# of Group 1 students (%)	# of Group 2 students (%)	# of Group 3 students (%)	# of low-skilled readers (%)	# of average-skilled readers (%)	# of high-skilled readers (%)
61. Each receptor has own shape [4]	3 (6%)	0 (0%)	0 (0%)	3 (19%)	0 (0%)	0 (0%)	3 (18%)
62. For a molecule to fit [4]	2 (4%)	0 (0%)	1 (6%)	1 (6%)	0 (0%)	1 (6%)	1 (6%)
63. It has to conform to that shape [4]	4 (8%)	1 (6%)	1 (6%)	2 (12%)	0 (0%)	1 (6%)	3 (18%)
67. Sweet receptors combine 2 parts [5]	3.5 (7%)	1.5 (9%)	0.5 (3%)	1.5 (9%)	1 (6%)	0 (0%)	2.5 (15%)
72. If either is missing [5]	10 (20%)	4 (24%)	2 (12%)	4 (25%)	1 (6%)	3 (18%)	6 (35%)
73. The receptor won't respond to sweet [5]	8 (16%)	3 (18%)	1 (6%)	4 (25%)	1 (6%)	2 (12%)	5 (29%)
77. Each receptor detects a specific taste [5]	9 (18%)	2 (12%)	2 (12%)	5 (31%)	1 (6%)	3.5 (21%)	4.5 (26%)

* Note: The 0.5 is a result of partial credit received for the idea unit.

Table 4.10

Total Instances of Recall of Main Idea Units

	Total instances of recall (%)	Group 1 (%)	Group 2 (%)	Group 3 (%)	Low-skilled readers (%)	Average-skilled readers (%)	High-skilled readers (%)
Instances of main idea recall (out of possible 900)	201 (22%)	73 (8.1%)	56.5 (6.2%)	75 (8.3%)	40 (4.4%)	68.5 (7.6%)	95 (11%)
Instances of recall of receptor main ideas (idea units 29, 61, 62, 63, 77) (out of possible 200)	30.5 (15%)	5.5 (2.8%)	9 (4.5%)	16 (8.0%)	3 (1.5%)	8.5 (4.3%)	19 (9.5%)

Given the low recall of *main* idea units, it was interesting to note which ideas, overall, were most highly recalled (see Table 4.11). The most commonly recalled idea units were familiar or concrete (readily visualized or understood) terms or phrases (e.g., sweet, sour), with the exception of new terminology such as umami, receptors, and T1R2/T1R3. The recall of these terms or idea units was significantly higher than the recall of the more abstract main idea units.

Table 4.11

Idea Units Most Frequently Recalled by Students (in Descending Order)

Idea unit	Total # of students who recalled the idea unit (%)	# of Group 1 students (%)	# of Group 2 students (%)	# of Group 3 students (%)	# of low-skilled readers (%)	# of average-skilled readers (%)	# of high-skilled readers (%)
14. Taste bud	46 (92%)	16 (94%)	14 (82%)	16 (100%)	15 (94%)	16 (94%)	15 (88%)
38. Sweet	37 (74%)	12 (71%)	12 (71%)	13 (81%)	12 (75%)	12 (71%)	13 (76%)
42. Umami	37 (74%)	13 (76%)	12 (71%)	12 (75%)	10 (63%)	13 (76%)	14 (82%)
39. Sour	34 (68%)	12 (71%)	10 (59%)	12 (75%	11 (69%)	11 (65%)	12 (71%)
40. Bitter	32 (64%)	10 (59%)	10 (59%)	12 (75%)	8 (50%)	11 (65%)	13 (76%)
12. [food] molecules	31 (62%)	11 (65%)	10 (59%)	10 (63%)	10 (63%)	9 (53%)	12 (71%)
41. Salty	30 (60%)	9 (53%)	10 (59%)	11 (69%)	10 (63%)	8 (47%)	12 (71%)
11. breaks down (the fruit)	25 (50%)	11 (65%)	6 (35%)	8 (50%)	4 (25%)	9 (53%)	12 (71%)
24. Receptors	25 (50%)	8 (47%)	7 (41%)	10 (63%)	4 (25%)	8 (47%)	13 (76%)
35. 10,000 [taste buds]	23.5 (47%)	9.5 (56%)	6 (35%)	8 (50%)	10 (63%)	8 (44%)	6 (35%)

(continued)

Table 4.11

Idea Units Most Frequently Recalled by Students (in Descending Order) (continued)

Idea unit	Total # of students who recalled the idea unit (%)	# of Group 1 students (%)	# of Group 2 students (%)	# of Group 3 students (%)	# of low-skilled readers (%)	# of average-skilled readers (%)	# of high-skilled readers (%)
31. Sends a signal	22 (44%)	10 (59%)	5 (29%)	7 (44%)	5 (31%)	9 (53%)	8 (47%)
32. To the brain	21 (42%)	10 (59%)	4 (24%)	7 (44%)	4 (25%)	9 (53%)	8 (47%)
13. Molecules float into taste buds	19 (38%)	7 (41%)	6 (35%)	6 (38%)	1 (6%)	9 (53%)	9 (53%)
45. Savory /yummy	19 (38%)	5 (29%)	6 (35%)	8 (50%)	3 (19%)	7 (41%)	9 (53%)
16. (Taste buds are) on the tongue	19 (38%)	7 (41%)	6 (35%)	6 (38%)	5 (31%)	9 (53%)	5 (29%)
74. For example, cats don’t have one part of sweet receptor	19 (38%)	7 (41%)	5.5 (32%)	6.5 (41%)	4 (25%)	4.5 (26%)	10.5 (62%)
76. So they aren’t interested in sweet food	18 (36%)	6 (35%)	5 (29%)	7 (44%)	2 (13%)	6 (35%)	10 (59%)
33. [signal] tells you something sweet is on the tongue	16 (32%)	8 (47%)	3 (18%)	5 (31%)	3 (19%)	7 (41%)	6 (35%)
70. T1R2	16 (32%)	8 (47%)	3 (18%)	5 (31%)	3 (19%)	7 (41%)	6 (35%)
71. T1R3	13.5 (27%)	4.5 (26%)	5 (29%)	4 (25%)	2.5 (16%)	3.5 (21%)	7.5 (44%)

Summary of Results from Content Analysis of Recalls

From a descriptive standpoint, Tables 4.9 and 4.10 show that Groups 1 and 3 learned more of the main ideas than Group 2, although the differences were small. There were greater differences in performance in relation to reading ability. Group 3, compared to Groups 1 and 2, recalled more of the main ideas related to receptors; however, a similar pattern in performance was revealed when students were grouped by reading level. The data thus suggests that reading skill plays an influential role in students' ability to grasp instructionally important ideas.

Furthermore, students are more likely to recall familiar or concrete ideas, as well as technical terms, after reading scientific text. In contrast, students in general are less likely to recall new, abstract ideas or concepts.

Correlations between Learning Outcomes and Reading Skill and Prior Knowledge

Up to this point, the results suggest that relevance instructions play some role in the learning that results from reading a science text. However, the qualitative data from students of different reading abilities and the content analysis of student recalls (Tables 4.9 and 4.10), suggest that reading skill may play a larger role in influencing that learning. My final research question asked how much of a role do reading skill and prior knowledge have compared to relevance instructions in determining student performance on learning measures?

An analysis of the correlations among the different factors showed that reading skill correlated most highly with almost all the learning measures (all correlations significant at $p < .01$): total ideas ($r = .529$), important ideas ($r = .457$), important ideas from paragraphs 1, 2, 4, 5 ($r = .549$), total details ($r = .504$), holistic score ($r = .545$), and Short-answer Question A ($r = .595$). The correlations were even stronger for performance on the MC/SA test: factual questions ($r = .715$), conceptual questions ($r = .740$), and total MC/SA score ($r = .801$).

Correlations between student scores and all the learning measures also support the influence of prior knowledge. Strong and significant correlations were found between the domain-question section of the PKQ and total recall ($r = .490$), important ideas from paragraphs

1, 2, 4, and 5 (r = .522), total details (r = .412), holistic score (r = .522), all the questions in Part 2 (Question A, r = 0.563, and B, r = 0.528); as well as the Part 3 MC/SA test (factual questions, r = .523 and conceptual questions, r = 0.622) (all correlations significant at the p < .01 level).

In contrast, the correlations between student scores and the relevance instruction treatment were quite low (all below .161), and none were significant.

Overall Summary of Results

I sought to investigate the effects of three different types of relevance instructions on students' learning from a science text. The generic instruction (to read for best understanding) and the specific instruction that targeted a core idea (the structure-function relationship) enhanced student learning in different ways. The generic instruction slightly improved students' factual learning (measured by the MC test), whereas the specific targeted instruction improved students' conceptual learning of the key ideas (seen in the MC test as well as through the qualitative content analysis of student recalls). The holistic instruction "to explain" resulted in poorer performance on all learning measures.

The qualitative analysis of student recalls when divided by reading level suggests that higher-level students make more effective use of relevance instructions, seen especially in the analysis of the low- and high-skilled reader recalls from Groups 2 and 3.

When analyzing specific main ideas, the data suggests that both the generic instruction and the RI that targets core ideas led to better learning of main ideas compared to the holistic instruction. However, the core idea instruction resulted in enhanced learning of the instructionally important ideas that were specifically targeted. Furthermore, the effect of reading skill (and prior knowledge) was found to be a significant factor in student learning from texts—

possibly mediating the effect of relevance instructions, and in general, outweighing the effect of the relevance instructions, as seen through the correlational data and through the comparison of main idea learning (Tables 4.9 and 4.10).

Chapter 5

DISCUSSION

Research has shown how contextual factors, such as the instructional task signaled through relevance instructions, can affect how students comprehend expository text (Hamilton, 1985; Kaakinen et al., 2002; McCrudden, et al., 2007; van den Broek, Lorch, et al., 2001). The goal of this study was to determine the relative effects of three different relevance instructions—one generic instruction and two discipline-aligned relevance instructions (i.e., those designed to orient students to the core ideas and principles of science)—on the conceptual learning and learning of key ideas of middle school students reading a science text. There was no statistically significant difference in the effect of the three instructions on middle school students' learning as measured by recall and direct performance questions; however, descriptively speaking, students who received the RI which targeted the core ideas did best on most of the learning measures, whereas students who received the explanation RI did poorly on most measures. The differences in performance were significant for the MC/SA assessment, such that students who received the generic instruction performed better on the factual questions and students who received the core idea instruction performed better on the conceptual questions. The influence of the relevance instructions was seen more distinctly in the qualitative analysis of the recalls. The holistic explanation instruction served as the main organizing proposition for some of the Group 2 students; whereas Group 3 students produced recalls with richer descriptions of the structure and function of receptors.

Although the results suggest the potential of targeted relevance instructions to improve learning of key ideas, this study also revealed the outsized role of reading skill (and prior knowledge) in influencing students' learning from text—affecting students' learning in general, and potentially mediating the effectiveness of the relevance instructions (seen in the qualitative analysis of recalls based on students' reading skill).

Relevance Instructions and Factual Learning

Regarding factual learning, Groups 1 and 3 performed similarly on different measures (recall and MC/SA questions). Based on the literature, Group 1 was expected to do well on factual learning because the generic instruction "to learn/understand as best as you can" would have likely suggested to some/most students that they retain as much of the content as possible. This may explain why Group 1 students recalled more of the initial ideas of the text—terms like *saliva* and steps such as *sending a signal to the brain*—even more so than Group 2 students who were asked to explain how we taste sweetness. Group 1 students scored highest on the factual MC/SA questions because they scored highest on questions related to the process of tasting (paragraph 2) and ideas from paragraph 3 that did not directly relate to tasting sweetness. The factual learning of Group 3, on the other hand, was also quite high—and higher than Group 1 on all recall measures. The students in Group 3, in general, paid more attention to the receptor-related material in paragraphs 3, 4, and 5 compared to the other groups.

The underperformance of Group 2 relative to the other two groups is more difficult to explain. One possible reason is that the explanation RI had an unintended *focusing effect* (Duchastel & Brown, 1974). Once students felt they had the basic information to explain tasting sweet, they may have disregarded other information (e.g., in depth information about receptors) that was not so explicitly related. An alternative reason is that with such an explicit, but general, instruction, students would have had to expend cognitive resources determining the relevance of information as they read (i.e., is this detail important to an explanation of tasting sweetness?)

which would limit the resources available for global comprehension (Van den Broek, Tzeng, et al., 2001).

Interestingly, the scores for factual learning among the three groups converged for recall of less important information (see Table 4.6, row 4 in the Results section). This is discussed in more detail in the section on interest and beliefs about what it means to learn science.

Relevance Instructions and Conceptual Learning

Explanation relevance instruction. There was evidence from the literature base that the use of relevance instructions that required higher-level integration of ideas would enhance conceptual learning (e.g., Harp & Mayer, 1998; Lehman & Schraw, 2002; McCrudden et al., 2006; effect sizes ranging from $\eta^2 = 0.04$ to $\eta^2 = 0.076$). Thus, it was hypothesized that the pre-reading instruction that prompted for an integrated explanation would facilitate students' conceptual and holistic understanding of the text. Yet, across all conceptual measures, Group 2 performed worse than Groups 1 and 3—notably on Performance Question A, which explicitly asked for an explanation of tasting sweet, and on the holistic measure, which among other things assessed the content and coherence of students' recalls.

I would have predicted Group 2 students to have had stronger recall of paragraph 2, which focused on the process of tasting sweetness; yet notably fewer students recalled facts from that paragraph, such as the saliva breaking down food, the food entering taste buds, or the food molecules attaching to receptor, which sends a signal to the brain. As mentioned earlier, one plausible explanation is that the instruction was too vague. Without a specific criteria for relevance, students would have to use cognitive resources to determine which information to attend to. And if information was not explicitly connected to tasting sweetness or obviously important (e.g., terms like saliva), then students may have prioritized other information—for example, information from paragraph 5 about needing T1R2 and T1R3 for a receptor to function.

The Group 2 students also had a marginally lower reading skill, compared to Groups 1 and 3, which may have played a role in their performance on conceptual questions. This will be discussed in the section on reading skill below.

Structure-function relevance instruction. Based on the literature and the logic of the study design, I would have expected that the structure-function RI would lead to a greater understanding of the role of the sweet receptor and the relationship between its structure and function—demonstrated by stronger performance on performance question B, and on the multiple-choice questions that specifically tested for those key concepts. As shown in the results, Group 3 performed slightly better than Group 1 on all the conceptual measures, and much better than Group 2, with a significant difference on the MC/SA conceptual questions. From a qualitative standpoint, the recalls of Group 3 students mentioned receptors more frequently and were richer in their description of the receptor's role. However, Group 3 students had notably low scores for performance question B, which questioned directly about the relationship between structure and function.

Difficulty of the structure-function relevance instruction. There were likely two main reasons why students in Group 3 (and students in general) performed so poorly on performance question B: it was 1) difficult to understand and 2) difficult to execute.

First, the structure-function relevance instruction was likely difficult to understand for a number of students. As noted in the findings, Question 10 of the PKQ revealed that 60 percent of students, notably the sixth- and seventh-graders, could not explain the phrase "structure affects function." The lower prior knowledge of the sixth- and seventh-graders might be expected given that the teaching of structure-function relationships often occurs in the context of teaching about the cell, and officially occurs in seventh grade according to the NYC K-8 Scope and Sequence Curriculum map (NYC Department of Education, 2008). Thus, even though the relevance instruction had been pilot tested on a sixth grader, students, in general, may not have had sufficient prior knowledge to support them in understanding the question.

Even though the relevance instruction and Question B were written in a more considerate fashion (i.e., "explain how the structure of sweet receptors is important to how they work"), students seemed to misinterpret the question in general, thinking that it asked *why* was the structure of receptors important rather than *how* it worked as seen from examples in the results section. This misunderstanding was not limited to lower-skilled readers. Some high-skilled readers also misunderstood the question, even though their recall reflected full understanding of the receptor's role (e.g., student 12).

Second, it was difficult to execute. Even if properly understood, this high-level relevance instruction places a high demand on a student's cognitive resources. Most students would have focused on understanding the text at a literal level, yet to answer a question like this, students would have had to understand the question, search for the relevant information, and then engage in higher-level cognitive processes (e.g., analysis, synthesis) of more distant segments of the text to formulate an answer. A higher-level relevance instruction such as this may be more successfully executed by higher-level readers, a tentative conclusion which the qualitative analysis of the data seems to support.

The answer also requires an explanation or a line of reasoning. Research on the construction of explanations and arguments shows that this type of explanation skill is difficult for students, and is best developed by explicit instruction and practice (McNeill & Krajcik, 2007). For this specific relevance instruction, students would have to focus on parts of the text that discussed the structure of the receptors and its role in tasting, and then transform that knowledge into an original explanation. Some students described the ability of receptors to distinguish tastes, rather than explicitly describing how the structure affected the function. This shows that the structure-function RI functioned for some students as a targeted RI because it oriented students to the important topic of receptors, even though it did not result in the degree of higher-level explanation/understanding that was intended.

The Effectiveness of the General Relevance Instruction

The data shows that the structure-function RI, which explicitly targeted core ideas, was most effective in facilitating student learning of key concepts. Yet, the general RI to "learn/understand the material as best as you can" was also shown to be effective in facilitating conceptual understanding compared to the other two instructions. The reason was likely due to students' heightened standards of coherence (van den Broek, Bohn-Gettler, Kendeou, Carlson, & White, 2011). Students may have put more effort into developing a coherent mental model because they knew they would be held accountable for what they learned (i.e., would have to write down what they learned). The goal of learning to one's best ability assumes a focus on main ideas, but also encompasses as many details as possible. And in contrast with the explanation RI, the students' field of focus encompassed the entire text, so students did not have to expend cognitive resources to determine what was relevant or not, as did students in Group 2.

The strong performance of students in Group 1 compared to Groups 2 and 3, especially on the conceptual questions, was also probably enhanced by the coherence of the text. The text was highly "considerate" (Armbruster & Anderson, 1988) in that it was written in a manner that was both coherent and accessible for students. The overarching purpose of the passage was clearly signaled in the first paragraph with the question "How do we sense sweetness?" with the remaining paragraphs devoted to cogently presenting the answer to the query. That, plus the initial activity designed to generate situational interest on the topic of sweetness, may have primed students, even if they received a general instruction, to focus on the topic of tasting sweet. Different studies (e.g., Ramsey & Sperling, 2014; Schellings, Van Hout-Wolters, & Vermunt, 1996a) have shown that middle and high-school students are sensitive to important ideas when reading texts for academic purposes, even when they are given alternate instructions that might draw attention away from the main ideas. Also, a number of studies have shown how increasing coherence of text benefits recall in general (e.g., Loxterman, Beck, & McKeown, 1994; McKeown, Beck, Sinatra, & Loxterman, 1992; McNamara, Kintsch, Songer, & Kintsch, 1996).

Relevance Instructions and Reading Skill

The importance of reading skill in the understanding of expository text has been well documented in the research literature (Daneman & Mierkle, 1996; Fox, 2009; Oakhill & Yuill, 1996) and may explain several patterns seen in student performance on the learning measures. Although ANOVA revealed no significant differences in reading skill among the experimental groups, Group 2 performed more poorly on all the learning measures compared to Groups 1 and 3. In some cases, the differences were significant, as in the case of the factual and conceptual questions of the multiple-choice test. One partial reason for the lower scores may have been the lower reading skill of Group 2 compared to Groups 1 and 3, even though the differences in reading skill were not statistically significant. Group 2 had a greater proportion of students in the lowest reading group tercile (8 out of 17; 47%) than groups 1 and 3 (24% and 25% respectively), and Group 2 had the fewest number of students in the highest reading group tercile (2 out of 17; 18%) versus Groups 1 and 3 (35% and 56% respectively).

Low-skilled readers. Research on reading skill and comprehension (of expository text) shows that there are notable differences between low- and high-skilled readers. Less-skilled readers tend to have fewer cognitive resources to process information in their working memory (Daneman, 1991). They have more difficulty accessing information from long-term memory (Anderson & Pearson, 1984; Spilich, Vesonder, Chiesis, & Voss, 1979) and are less adept at recognizing expository text structures and main ideas (see review by Seidenberg, 1989). In addition, they may possess lower standards of coherence or have fewer strategies to deal with a break down in coherence of a text (e.g., Oakhill, 1983).

The effect of these challenges for low-skilled readers is heightened with science texts, as opposed to other disciplines, because of the density and complexity of new, unfamiliar information. One essential component of comprehension is that readers connect and relate information in a coherent manner (Best et al., 2005; Zwaan & Singer, 2003 cited in Ozuru et al., 2009). The conceptual density of science texts, the conceptual load of terms, and the unfamiliarity of terms and concepts makes it difficult for students with limited cognitive resources (both WMC and prior knowledge) to integrate the new and multiple ideas as they read, or to adjust their processing strategies as they read (Gomes & Mensah, 2016; Linderholm & van den Broek, 2002).

Although the number of participants did not allow a quantitative analysis of the scores of low- versus high-skilled readers, differences could be seen in a qualitative analysis of their recalls. As seen in Tables 4.9 and 4.10, high-skilled readers tended to remember more details overall, especially information from paragraph 5, which may reflect a greater WMC and more efficient or effective processing of content. Less-skilled readers tended to provide simpler facts about the process of tasting sweet. Interestingly, they recalled technical details such as 10,000 taste buds, and the term umami as well as the high-skilled readers, likely due to factors such as novelty or concreteness, which will be discussed below.

Based on their recalls, it appears that the low-skilled readers had difficulty processing or executing the relevance instructions. Research shows that when reading for specific purposes or with a specific goal, low-skilled readers may have more difficulty with additional demands placed on their reading (e.g., Budd, Whitney, & Turley, 1995). This was seen in the recalls of low-skilled readers. A number of the low-skilled readers from Group 2 gave almost no indication that they internalized the relevance instruction (e.g., student 44). In other instances, students attempted to explain sweetness, and were oriented to the correct main ideas, but they had a difficult time marshaling ideas into a coherent explanation to varying degrees as shown in the recall of student 36 in the Results section.

High-skilled readers. In general, high-skilled readers are more able to handle global or additional processing demands, which seems to be confirmed by the performance of high-skilled students, particularly in Group 3. These high-skilled readers made more references to the role of sweet receptors or the shape of receptors or food molecules in their recalls and in their answers to Part 2 questions compared to the low-skilled readers of Group 3 and the high-skilled readers in Groups 1 and 2. The data suggests they were able to adopt the instruction, identify and process relevant information in the text, and encode and retrieve information more effectively in and from their knowledge structures. Overall, the qualitative analysis indicates that reading skill may influence the effect of relevance instructions, such that students of higher-reading ability are able to execute relevance instructions more effectively.

Other Factors that Affect Comprehension

In the results section, I noted the variety of answers that resulted within a particular RI group; students seemed to have been influenced by the RI to varying degrees. As described above, reading skill seemed to mediate the effect of relevance instructions, and as seen through the correlational data, reading skill, in general, played a strong and significant role in comprehension of the text. In contrast, the relationship between the relevance instruction treatment and various learning measures was quite weak. Aside from reasons such as text characteristics and reading skill, other reasons for the lack of a discernable relevance effect of the relevance instructions may have been other reader factors that affect comprehension, such as prior knowledge, interest, and to a lesser degree, student beliefs about learning. How each factor interacts with relevance instructions will be discussed in turn below.

Prior knowledge. As mentioned in the literature review, prior knowledge in the form of domain- and topic-knowledge plays a critical role in comprehension, particularly for conceptually dense and unfamiliar expository text (Ozuru et al., 2009; see also references from Best et al., 2005). Often, a reader has to access prior knowledge to provide the scaffolding and meanings necessary to fully understand such texts. In this study, it was assumed that participants would hold little prior knowledge of the topic of tasting sweet. The domain-based questions of the PKQ revealed that students held tenuous understandings of science concepts, such that, even when provided relevance instructions, students would likely struggle to form a mental model of the text. For example, although students demonstrated some formal exposure to terms such as cell (12, 13, and 9 students in Groups 1, 2, and 3 respectively), fewer had a solid grasp of the word molecule (7, 6, 3), and most were unfamiliar with specialized terms like receptor (5, 3, 3) and conform (3, 4, 3). Yet the terms molecule and receptor appear in the initial description of tasting sweetness (paragraph 2), and are then constantly referred to for the remainder of the text. If students had difficulty visualizing a molecule in relation to a taste bud and taste cell, they may have also had difficulty visualizing or understanding how molecules and receptors attach to each other, and the related concepts of how receptors are able to discriminate different types of taste.

The qualitative analysis of the recalls allowed for a more nuanced understanding of how prior knowledge influenced the character of students' learning. Table 4.6 showed the idea units most frequently recalled by students. It is clear that students readily recalled ideas that pre-existed in their knowledge structure (taste buds, sweet, sour, brain, cats, etc.). Furthermore, the initial sentences of student recalls often began with such concrete, familiar information. This effect of prior knowledge on subsequent learning is described in Schallert's schema theory, which posits "one's existing knowledge influences directly the content and form of new knowledge" (Schallert, 1982, p. 14). Since much of the information presented in a science text is likely to be new to students, a student's prior knowledge may have a greater influence on how he or she processes the text. For example, the recall of student 32 (see page 82), who received the general RI, was organized around the concept of taste buds and omitted any intermediary information about food molecules or receptors in the process of tasting.

The importance of scaffolding new information to students' presumed prior knowledge was demonstrated by the exceptionally high recall of umami. Because umami was presented in the context of the other four tastes, students may have found it relatively easy to assimilate the information about the new—however foreign— information about the taste into their existing, activated knowledge structure. Another reason may be due to its novelty, which will be discussed below.

The strong and significant correlations found between prior knowledge and the learning measures in this study also confirmed the importance of prior knowledge in learning from science texts. These results support the findings of Tarchi (2010), who showed that—aside from reading skill—a reader's prior knowledge of the meaning of key concepts, as well as their ability to judge the correct meaning of a word in context (lexical inferences) were among the strongest factors that influenced students' comprehension of science texts.

Interest and beliefs about what it means to learn science. Another factor that helps to explain recall patterns in the data relates to situational interest. Although students may not have a personal, intrinsic interest in the text's content, certain features of the content can help to foster situational interest, which enhances recall (Alexander & Jetton, 1996). In particular, information is found cognitively interesting if it presents novel or discrepant information (e.g., the case with umami), or if it presents information in a vivid way (W. Kintsch, 1998; Anderson, Shirey, Wilson, & Fielding, 1984; Schraw et al., 1993). Information is also recalled more easily if it is concrete (Hidi & Baird, 1986; Sadoski, 2001) as opposed to being generalized and abstract. The results supported such findings. For example, a number of students recalled steps in the process of tasting sweet related to the tongue, taste bud, or brain (~35 – 50%); but a lower percentage remembered the steps related directly to the receptor (25%) or the definition of a receptor (2%). Similarly, in studies by Hidi and Baird (1986, 1988), sixth grade students had a harder time recalling abstract information. A number of students recalled that "Morse invented the telegraph because he did not like how long it took to send people message through the mail". However, only a few recalled that "Morse knew that the only way to have a faster type of communication was to use electricity," and the subsequent sentences that discussed electricity were rarely mentioned by the students.

Concrete, numerical details were also remembered more easily. In this study 47% of students recalled that there were 10,000 taste buds on the tongue. In the previously mentioned Hidi and Baird study, when the researchers changed the sentence "Thomas Edison became the most famous inventor of all time even though he left school when he was very young" to "Thomas Edison became the most famous…left school when he was only 6 years old", recall increased from 57% to 87%. In general, Tables 4.9 and 4.11 seem to support the idea that concreteness or familiarity had a significant role in the recall of ideas, and that their effects surpassed that of the relevance instructions.

Lastly, student beliefs about what is means to learn science may have also played a role in the nature of student recalls. Aside from the high recall of familiar terms or concepts, students tended to recall technical details, such as molecules (63%), 10,000 (46%), and T1R2/T1R3, (32%/27%). Studies by Dee-Lucas and Larkin (1986, 1988a) suggested that novices develop a rudimentary "content schema" (Kieras, 1985) that they use to identify important information within a given content-area text. They found that novice physics undergraduate students, when reading physics texts, placed importance on equations, facts, and definitions, that is, terms that are readily identifiable as being "scientific". It may be that middle school students also possess a content schema regarding scientific texts, which makes them believe that technical terms and numbers are important to learning science, and thus to pay more attention to them.

Recall of Main Ideas

One of the most salient findings of this study, and particularly relevant to the use of texts in science education, is that students had low recall of important ideas, even when important ideas were signaled by the relevance instruction. Students, overall, recalled 29% of the main ideas in the text and 21% of the total ideas in the text. This finding supports the findings of other studies that demonstrated the low recall of important ideas in expository text (e.g., Alexander and colleagues, 1994a; Garner et al., 1989; Hidi and Baird, 1988). Students had difficulty grasping the key ideas that would likely be the instructional objective of having students read the text. One of the primary purposes of the text was to describe and explain the role of the receptor in tasting sweet. Yet as described in the results section, for each paragraph, the key idea units related to the receptor was recalled the least— especially the ideas in paragraph 4, which were critical to the understanding of how receptors were able to distinguish various tastes. And though the relevance instructions, particularly the structure-function RI, seemed to influence some students to attend to core ideas, they appeared most effective for the higher-skilled students.

Significance of the Study

The current study contributes to the literature on relevance instructions and on reading in science in the following ways:

Previous research has provided understanding of how relevance instructions help to facilitate students' comprehension of expository text. This study sought to explore whether relevance instructions could be used in service of science instruction, i.e., be specifically designed to enhance the learning of the cross-cutting concepts, core ideas and principles of science that are emphasized in the K-12 Framework and NGSS (NRC, 2012; NGSS Lead States, 2013). The quantitative analysis did not reveal any significant differences among the three relevance instructions in terms of learning outcomes for the recall or short-answer measures (although the differences approached significance for the recall of main ideas). There were, however, significant differences in learning for the MC/SA test. Students given the discipline-aligned RI focused on core ideas performed the best on the conceptual questions and those given the explanation RI performed the most poorly. The generic instruction to "understand as best as you can" functioned relatively well compared to the discipline-aligned instructions. The qualitative analysis also suggests that main idea relevance instructions can draw students' attention toward key ideas and details, especially for higher-skilled readers.

The majority of studies on relevance instructions has been conducted with college level students, whereas the current study used middle school participants. More research with secondary school students is needed, especially with the call for increased expository reading in grades 4 – 12 [see Common Core State Standards for English Language Arts and Literacy in History/Social Studies, Science and Technical Subjects (CCSSO & NGA, 2010; corestandards.org); Heller & Greenleaf (2007)]. Compared to college students, middle school students face greater challenges in comprehending science texts because they have had less exposure to academic vocabulary and text structures and because their reading skill is less developed. I was interested in seeing whether relevance instructions could serve as one means of facilitating their conceptual and disciplinary learning. The results of this study provide a starting point for future explorations of the effect of science-aligned relevance instructions for this population of students.

Additionally, this study provides more insight into the usefulness of different types of relevance instructions for students of different reading abilities. The higher-level instructions seemed to benefit more-skilled versus less-skilled readers to a greater degree. Reading skill not only influences comprehension in general (as shown in the correlational data), but also seems to mediate the effectiveness of relevance instructions.

Finally, this research adds to the small body of literature analyzing/documenting how middle school students read science texts and the different factors that affect their comprehension. The qualitative analysis of student recalls provides more insight into what ideas that students grasp when reading science texts. The results support previous findings that students focus on concrete and readily identifiable ideas, and that abstract concepts are not easily learned from text, even when they are strongly signaled as important ideas. The relevance instruction that pointed to an abstract, yet central concept, seemed to facilitate the learning of that concept for students, although more so for the high-skilled readers.

Implications for science teaching. These findings have important implications for science teaching. Teachers may use relevance instructions as one means of supporting student learning of important standards-based ideas. Among the three types of relevance instructions, an instruction that explicitly focuses students' attention to the core ideas in the text seems to be most effective. However, the effect of orienting students, as seen in the recalls, did not necessarily lead to a statistically significant improvement in the performance of students on various learning measures (short-answer and multiple-choice tests) compared to other types of instructions. The holistic instruction *to explain* seems to have had a slightly detrimental effect on student learning compared to the other two types of instructions—perhaps because it narrowed students' criteria for learning or placed more demands on students cognitive processing in determining relevance.

Teachers should also note that the relevance instructions had different effects for different levels of reading skill. Relevance instructions seemed to benefit high-skilled readers more than lower-skilled readers--although they were not uniformly beneficial for all high-skilled readers. The results also showed that there was some influence on low- and average-skilled readers. Higher-skilled readers were more likely to learn the main ideas of the text without any specific relevance instructions (as seen in Group 1), but were more likely to learn particular important, yet abstract ideas if provided specific relevance cues (as seen in Group 3). In general, the study confirms that reading skill (and prior knowledge) play an outsized role in comprehension of science texts and probably mediates the effect of RIs. The importance of reading skill was also recently confirmed by Hall et al. (2016). Thus, teachers need to consider ways to support the learning of key instructional ideas—particularly for low- and average-skilled readers, e.g., through the use of diagrams (Butcher, 2006); a pre-review of important vocabulary, or a post-reading discussion of core disciplinary concepts (see for example, Harvey & Goudvis, 2007, or McKenna & Robinson, 2014, for an overview of strategies). Explicit teaching of expository text structures (Williams et al., 2005) might also help students to identify important ideas. Teachers may also consider modeling comprehension strategies through shared readings of science texts (Fisher, Frey, & Lapp, 2008, Lapp, Fisher, & Grant, 2008) or to train students in methods that have been shown to be effective in helping students to comprehend expository texts [e.g., Reciprocal Teaching, Palincsar & Brown, 1984, 1989; or Self-Explanation Reading Training (SERT), McNamara, 2004b; McNamara & Scott, 1999]. Research shows that components of these strategies, which include actively asking questions and summarizing, can help students to become better readers of science texts (Pressley, 2000).

Implications for textbook writers. This study also has implications for textbook writers; namely, that relevance instructions that target core ideas may be effective in directing some students toward key ideas. Second, a holistic instruction such as the one to explain an entire process or sophisticated concept may be less productive for students. The findings of this study provide some support for the current practice of using lower-level targeted relevance instructions (i.e., those that require recall of simple facts or concepts) as a bridge to later building a more sophisticated or robust mental model of the abstract, scientific concept. Lastly, students may need stronger signaling cues (such as explicit headings, bold-faced terms, or diagrams) to direct attention to the important, abstract concepts in the text—although research suggests that students need to be trained in the use of these cues in order to truly benefit from them (Kelley & Clausen-Grace, 2010; McTigue & Flowers, 2011).

Limitations

There were a number of limitations of this study, which are elaborated below.

Sample size. Given the small to moderate effect of relevance instructions mentioned in the literature, an a priori power analysis suggested that a sample of at least 90 students (three groups of 30 to detect an effect size of 0.33 at $p < .05$) would be needed to generate statistically significant results. Because of limitations in working with New York City public schools, I was only able to recruit around half that number ($n = 50$) despite using eight research locations. As a consequence, even if the relevance instructions exerted a real effect, the analysis did not have enough power to reveal statistically significant differences. The small sample size also limited a comparison of the less- versus more-skilled readers for each of the treatment groups.

With a larger sample, the study may also have yielded more valid results. Differences in reading skill among groups may have been minimized, which seemed to skew the performance scores of Group 2. Also, a larger sample that included eighth grade students may have yielded more meaningful results from the structure-function relevance instruction and performance question B.

Measures. There were several weaknesses in the reliability of the instruments to measure learning.

Recall. One drawback for recalls is that students who have difficulty expressing their ideas in writing would be disadvantaged (e.g., some students would demonstrate more understanding if assessed orally). For example, student 52 wrote, “The taste cells have structures like sweet, salty, bitter, sour, and umamim." It is likely that "structures" is referring to "receptors", but it's not entirely clear from the sentence or the surrounding context.

I also could have had students complete a formal distractor task between the reading of the text and the subsequent recall, which would have cleared the student's working memory. Without a distractor task, the recall might reflect trace memory, particularly for content appearing toward the end of the text.

Holistic measure. The holistic score provided an overall rating of the accuracy and coherence of the student's mental representation of tasting sweetness. However, a unitary score was not the most ideal way to capture the various dimensions (e.g., accuracy, coherence/organization, elaborateness) that were represented by that rating. In a few instances, recalls were difficult to score because of differences in performance among those dimensions.

Performance questions. Some of the major weaknesses of the short-answer performance questions were described earlier in the discussion (i.e., students misinterpreting the question related to structure and function). Thus, the comprehensibility of the questions (and the RIs) needed to be more rigorously tested prior to the study.

Format. As a final note, the text-reading and test-taking protocol of Session 3 was cognitively demanding, and students may have experienced some test-taking fatigue. The research, moreover, was conducted afterschool in a "lab-like setting" which does not necessarily reflect authentic classroom contexts.

Experimental text. Although the single short passage used in this study was authentic and could be considered representative of what teachers might provide to students, the study would have been more valid had several sample texts been used, which varied in content and which had been counterbalanced among groups. Moreover, the conclusions would have been more generalizable if the research were conducted with texts of different lengths, or with texts taken from different subfields of science (e.g., physics as well as chemistry or earth science). The relevance instructions were somewhat artificial in that they were designed specifically for this particular text, also reducing the study's generalizability. However, even if texts from different scientific disciplines were used, the primary goal of "explanation" would likely still apply. The relevance instructions could also be designed to focus on core disciplinary ideas based on the K-12 Framework or the NGSS.

Future Research

Aside from replicating the study with modifications using a larger sample, the current study suggests several other possibilities for future research. The explanation RI was intended to prompt students to construct a coherent and integrated mental representation of the text content. This study found no difference between the general and science-aligned RIs in this regard—the major possible reasons being that the general instruction likely heightened students' standard of coherence and because the text itself was highly considerate. A future study that employed less considerate text (e.g., which did not clearly signal the main topic or which required more inferencing on the part of students) might reveal a true discernable benefit of a holistic relevance instruction. It would also help to compare these instructions to a control group that did not receive any instructions at all.

Future studies should continue to investigate different types of relevance instructions for different populations of students (e.g., higher grades or less- versus more-skilled readers). For example, it may be more beneficial for sixth graders, or for less-skilled readers, to use lower-level targeted instructions for main ideas instead of a higher-level targeted instruction or instead of a general, holistic instruction. Or, a holistic instruction could be used in conjunction with targeted RIs (e.g., “Explain how you are able to taste sweetness. Be sure to include the steps in the process and describe the role of the receptor). Since this study suggested that higher-level instructions were more effective for more-skilled readers (who likely can handle the greater cognitive demands), future studies should examine the effect of these type of instructions for eighth grade students or higher, since they would likely have more exposure to academic vocabulary and text structure, as well as be more automated in their reading skills than sixth graders.

Research that incorporates interviews of students or think-alouds would also help to elucidate how relevance instructions influence students’ processing of the text and why they have differing effects on different students. For example, I would have wanted to ask students in Group 2 how they determined which information was important to explaining how we taste sweetness. It would also be interesting to provide the text to a group of students and ask them to identify what they regarded as important information.

As mentioned above, further studies are needed on multiple texts from the same science discipline, or on texts from different science disciplines to make the results more generalizable.

And finally, given that the results of the study confirm how difficult it is to grasp main ideas in a science text, further intervention studies on how to improve students’ comprehension of core ideas (e.g., teaching summarization skills) would be worthwhile.

Conclusion

In this study, a general relevance instruction and two discipline-aligned relevance instructions were shown to have varying effects in helping students to learn factual and conceptual information from a science text. The higher-level RI that focused on key ideas appeared to be most effective in orienting students to those instructionally relevant ideas, whereas the integrative, explanation RI was the least effective. Factors such as reading skill held a significant role in students' comprehension of the text, and also appeared to mediate the effect of the relevance instruction. A qualitative analysis of student recalls suggests that the relevance instructions helped some students, notably higher-skilled readers, to develop a richer understanding of the instructionally important portions of the text, and may have influenced their overall approach to understanding the text.

This study highlights the need for thoughtful instruction before and after reading, in order for students to truly grasp the core disciplinary ideas in the text. Science teachers can anticipate that students, when given a reading assignment, will focus on a mix of prior known facts, concrete ideas, and interesting points, in addition to important ideas. The use of relevance instructions that are aligned with disciplinary aims, particularly those that identify core ideas, seem to provide a marginal or beneficial aid in helping students to focus on those ideas or principles; however, more research is needed to characterize its potential benefit.

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Appendix A

Recruitment Procedure

Introductory Session: Obtaining Student and Parental Consent

Hi everyone. My name is Mr./Ms. ____________ and I am a researcher from Teachers College, the School of Education at Columbia University. Mr./Ms. (afterschool coordinator) has agreed to let me come work with you on a research study over the next few weeks. I am basically interested in learning more about how students read and learn from science texts. How many of you find your science textbook easy to read? [Wait for answer.] How many of you find the textbook hard to read? [Wait for answer.] Well, I hope that what I learn from my research can be used to improve science text books and also help students like you to understand them better.

The reason why I am here today is that I would like to ask whether you would like to participate in my study. First, let me describe the study in more detail. The study would take place afterschool in three separate sessions. In the first session, you would take the first part of a standardized reading test. You would also answer a brief questionnaire about a science topic. In the second session, you would complete the second part of the standardized test. Then in the third session, you would read a passage from a science text and answer some questions afterward. All the sessions have lasted from 40 minutes to one hour at most.

I want to stress that you don't have to be "good at science" or "good at reading" to participate. Anyone can take part. Also, all of your answers to the questions and your scores would be kept confidential. Your teacher or parents will not be told how you did. No information that identifies you will be included in my dissertation. And of course, this would not affect your grade at all. This is just for my research project.

If you would like to participate, you would have to fill out this consent form. The form first describes the research and then describes your rights as participants. Your parents have to sign this as well. If you decide that you would not like to participate, you will just participate in your regularly scheduled afterschool activity.

Why don't we read through the consent form? If you have any questions about this research project, you can ask after we read this.

[Have different students read different paragraphs and answer any questions.]

Thank you everyone for your time.

Appendix B

Sample Parent Consent Form

Research project: Pre-reading Instructions and Their Effect on Learning from Science Texts

Teachers College, Columbia University
525 West 120th Street
New York NY 10027
(212) 678-3000/ www.tc.edu

PARENTAL INFORMED CONSENT FORM – RESEARCH DESCRIPTION

Dear Parent/Guardian:

My name is Yuna Lyons and I am a Ph.D. candidate at Teachers College. I would like to invite your child to participate in a research study that I will be conducting in the afterschool program at your child's school ____________________________ this semester.

DESCRIPTION OF THE RESEARCH:

The title of my study is: Pre-reading Instructions and Their Effect on Learning from Science Texts. Students often find their science texts challenging to read. Thus, the goal of my research is to determine what type of instructions—provided before reading—might be most effective in helping students to learn the key ideas and details of the science text.

The study would take place in three afterschool sessions. In the first session (~ 60 minutes), participants will be asked to take the first part of a standardized reading test. They will also fill out a brief questionnaire to determine their knowledge of a particular science topic. In the second session (~ 45 minutes), students will take the second part of the standardized reading test. In the final session (~ 45 minutes), they will be asked to read a science passage and to answer questions about that passage.

The sessions will be conducted by me, Yuna Lyons, in one of the classrooms designated for the afterschool program. The principal of the school has approved this study to take place in the afterschool program. The research will not affect instructional time during regular school hours.

RISKS AND BENEFITS:

The research offers the same risks and benefits as any typical classroom activity. Your child may experience boredom or fatigue. On the other hand, they will have the opportunity to learn something new from reading the science passage. Furthermore, the results of this study may help science teachers to better understand how to use instructions to support student learning from science texts.

Any data collected will be used for research purposes only, and will not affect your child's class grades in any way. Your child's answers and scores will be kept confidential from the afterschool teachers, class teachers, school administration, and other students.

Your child's participation is completely voluntary. There is no penalty if your child chooses not to participate. If your child chooses not to participate in this study, or if you do not grant permission for your child to participate, he or she will do the regularly scheduled activities of the afterschool program. In addition to obtaining parental consent, the *assent* of your child will also be obtained on the first day of the research. Your child may withdraw from the study at any time with no consequences.

PAYMENT: A pizza party will be held as an expression of thanks for students who participate in the study.

DATA STORAGE AND CONFIDENTIALITY:

If your child participates in this study (with your permission), his or her answers and scores will be kept confidential. Instead of using their name, participants will be given a number that they will put on all the papers they fill out. Once the study is over, the data will be kept in my possession and will not be made available to your child's teachers, school administrators, or other students. All papers and data will be kept in locked files when not being used. The data will be destroyed after the minimum holding period of three years.

TIME INVOLVEMENT: The study will take place during three afterschool sessions as described above, within a span of three weeks.

(see over)

Teachers College, Columbia University
Institutional Review Board
Protocol Number: 13-305
Consent Form Approved Until: 07/16/2016

HOW THE RESULTS WILL BE USED:
The data and results of the study will be used for my doctoral dissertation. The data and results may also be presented at meetings or published in journals or articles, but in such an event, no personally identifiable information will be used.

Please read through the Participant's Rights listed below, with your child. If you grant permission for your child to participate in this study, you should sign this form at the bottom. Your child should return it to the specially designated box at the afterschool program.

A copy of this Parental Consent Form has been included for you to keep for reference.

Please feel free to contact me at 646-318-5742 or at yhl2104@columbia.edu if you have any questions about this research.

Sincerely,

Yuna Lyons, Ph.D. Candidate
Science Education Program, Teachers College

PARTICIPANT'S RIGHTS:

- The researcher read the Research Description to me. I have had the opportunity to ask questions about the purposes and procedures regarding this study.
- My participation in this research is voluntary. I may refuse to participate or withdraw from participation at any time without penalty in the afterschool program.
- The researcher may withdraw me from the research at her professional discretion.
- If, during the course of the study, significant new information becomes available that may relate to my willingness to continue to participate, the investigator will provide this information to me.
- Any information derived from the research project that personally identifies me will not be voluntarily released or disclosed without my separate consent, except as specifically required by law.
- If at any time I have any questions regarding the research or my participation, I can contact the investigator, who will answer my questions. The investigator's phone number is (646) 318-5742.
- If at any time I have comments or concerns regarding the conduct of the research or questions about my rights as a research subject, I should contact the Teachers College, Columbia University Institutional Review Board /IRB. The phone number for the IRB is (212) 678-4105. Or, I can write to the IRB at Teachers College, Columbia University, 525 W. 120th Street, New York, NY, 10027, Box 151.
- I should receive a copy of the Research Description and this Participant's Rights document.
- The data collected in this research (written materials) will be viewed only by the primary investigator and members of the research team.
- The written materials [please check one]:
  ☐ may be viewed in an educational setting outside the research
  ☐ may NOT be viewed in an educational setting outside the research. (Your child may still participate in the study, even if this box is checked.)

☐ *YES, I GIVE PERMISSION FOR MY CHILD TO PARTICIPATE.*
I have read the above information and I give permission for my child to participate in the study entitled *"Pre-reading Instructions and Their Effect on Learning from Science Texts"*

______________________________	____________________
Parent/Guardian signature	Date
______________________________	____________________
Parent's Name	Student's Name

Appendix C

Text and Instruments

Instructions: Please read the article and try to understand it as well as you can. You will be asked to write what you learned.

Draw a small star in the upper right corner of this page, so that I know you have read these instructions.

Sense of Sweet: It All Starts with the Tongue

Who doesn't love sweets? From a creamy ice cream cone to a ripe banana, we all love that yummy sweet taste. But how do we sense sweetness?

A lot happens on your tongue when you eat a sweet, ripe banana. As you chew, your saliva breaks down the fruit into separate molecules. The molecules float into your taste buds, which sit on the little bumps you can see on your tongue. Under a microscope, a taste bud looks like an onion with a small opening at the top. Inside the taste bud are taste cells, which contain different kinds of receptors. Receptors are structures that receive and attach to specific substances. When a food molecule from the banana drops into the taste bud, it fits into its matching receptor, like a key into a lock. This starts a process that sends a signal to the brain, which then tells you there is something sweet on your tongue.

Your mouth contains about 10,000 taste buds. Each one has receptors for all five tastes: sweet, sour, bitter, salty, and something called umami (pronounced oo-MOM-ee). The taste of umami was identified by a Japanese scientist. It is the savory or yummy taste that we find in foods like meat broth or cheese. Most foods spark reactions in more than one kind of receptor. For example, a tomato has molecules of sweetness, sourness, saltiness, and umami. As a tomato ripens, the balance changes. There is less sour, more sweet, and more umami.

A banana has several different kinds of sugar. All of these different sugar molecules fit neatly into the sweet receptors on your tongue. A sugar molecule will fit in a sweet receptor, but not in a sour or bitter receptor. This is because sweet, salty, sour, bitter, and umami receptors each have their own shape. For a molecule to fit into the receptor, it has to conform to that shape.

Our understanding of taste has advanced rapidly in the last ten years. One breakthrough was the discovery that sweet receptors in mammals combine two proteins, labeled T1R2 and T1R3. If either part is missing, the receptor won't respond to sweet molecules. For example, cats don't have the T1R2 protein and so they have no interest in sweet foods.

Post-Reading Test 1

Directions: Please write what you learned from this article. Include as much detail that you remember from the text as possible. Don't worry about spelling or punctuation. Use the back page if necessary. There is no time limit.

Once you are finished, place this sheet in the large envelope and continue with the next page.

Post-Reading Test 2

Directions: Please answer the following questions (A-D). You may use the back of the page if needed. After you are finished, place this sheet in the envelope and continue with the next page.

A. Explain: How are we able to taste sweetness? Answer as fully as you can.

B. Explain how the structure of sweet receptors is important to how it works.

C. What was a recent and important discovery about sweet receptors in mammals?

D. Why does a lemon taste sour and not sweet? Use the word "receptor" in your answer.

Once you are finished, <u>place this sheet in the large envelope</u> and continue with the next page.

Post-Reading Test 3

Directions: Please circle the letter of the best answer for each item in this section.

1. What is the author's purpose in writing this text?
a. to explain why cats are not interested in sweet foods
b. to explain how we are able to taste sweetness
c. to explain why foods taste the way they do
d. to describe the five types of tastes

2. Which step is *not* a part of the process of how a sugar molecule is tasted as sweet?
a. saliva breaks down food into molecules
b. food molecules enter the taste buds
c. food molecules fit into taste receptors
d. a sugar molecule travels to the brain

3. Where are taste receptors located?
a. in taste buds
b. on sugar molecules
c. on T1R2 proteins
d. in the brain

4. What are the structures that "receive and attach to specific substances"?
a. sugar molecules
b. taste buds
c. receptors
d. food molecules

5. Why doesn't salt taste sweet?
a. the salt doesn't fit the shape of the sweet receptor
b. the salt blocks sugar molecules from the sweet receptor
c. salt has sweetness, but the brain can't sense it
d. salt doesn't fit through the opening of taste buds

6. What happens to the taste molecules in tomatoes as they become more ripe?
a. The amount of all the taste molecules increases.
b. The balance of taste molecules changes.
c. The taste molecules move closer to the surface.
d. The taste molecules break down more easily in the mouth.

7. What would happen if the shape of all the sweet receptors in your tongue were somehow changed?
a. There would be no change in the ability to taste sweetness because the shape of the sweet molecule has not changed.
b. There would be no change in the ability to taste sweetness because the sweet molecule can attach to the other receptors.
c. The ability to taste sweetness would be reduced because the sugar molecule could no longer attach to the sweet receptor.
d. The ability to taste sweetness would be reduced because the sugar molecules would be free to attach to all the other receptors.

8. Which of the following is the best explanation of why we are able to taste the sourness of a lemon?
a. There are no sugar molecules to block the taste of the sour molecules.
b. The sour molecules fit the shape of a sour receptor, which sends a signal to the brain.
c. The sour molecules spread more quickly than the sugar molecules.
d. The sour molecules fit into a sweet receptor in a strange way, which sends a signal to the brain.

9. If you look at a taste bud under a microscope, what does it look like?

10. Describe the taste of umami.

11. List the kind of taste molecules you would find in pizza.

12. Explain why cats cannot taste sweetness, even if they eat something sweet.

13. There is a diet pill that, after a person takes it, reduces his or her ability to taste sweetness in foods. How do you think this pill works?

Please answer this final question that is unrelated to the reading passage:
14. When your teacher gives you a reading assignment from a science text, which of the following statements best describes you? (You can choose more than one.)
a. I read carefully because I want to understand the content of the reading.
b. I read carefully because I want to be able to answer the questions that the teacher assigns us.
c. I read quickly and focus on the parts that will help me answer the questions that the teacher assigns us.
d. None of the above. If so, please explain briefly.

Thank you for your participation! Please sit or read quietly until everyone is finished.

Appendix D

Prior Knowledge Questionnaire

Directions: Please answer the following questions to the best of your ability.

1. What are the different tastes that your tongue can detect?

2. What structures in your tongue help you to taste food?

3. How are we able to taste sweetness? Write down anything you know about how you can taste sweetness.

4. Why doesn't sugar cause a sour taste in your mouth?

5. What do you think a molecule is?

6. What is a cell?

7. Which do you think is bigger, a molecule or a cell?

8. What do you think a "receptor" is? You can use an example to help your definition.

9. What do you think the word "conform" means? If you can, provide an example of something that conforms to your hand.

10. In science class, you may have heard the phrase "structure affects function." What does that mean? Can you provide an example?

Answer Key for Prior Knowledge Questionnaire

Test of Topic Knowledge (Questions 1 – 4)

1. What are the different tastes that your tongue can detect?

Answer: Sweet, salty, sour, bitter, and umami

1 pt – 4 or 5 tastes
0.5 pt – 3 tastes
0.25 pt – 2 tastes

2. What structures in your tongue help you to taste food?

Answer: taste buds, taste receptors

1 pt – taste receptors
0.5 pt – taste buds

3. How are we able to taste sweetness? Write down anything you know about how you can taste sweetness.

1 pt – if student mentions anything about taste receptors attaching to food (molecules)
0.5 pt – mentions any step in mechanism (e.g., such as taste buds attach to molecules and a signal is sent to the brain)
0 pt – our taste buds detect it

Note: This question is meant to test for students' knowledge of the sweet receptor mechanism, so give 0 credit for answers that solely mention the taste bud, or for answers that relate to the tongue having different areas that taste different tastes (which is a common misconception).

Examples:

- Our taste buds put it in sensors and sends a signal to the brain. → 1 pt
- Certain taste buds detect chemicals in the food that taste sweet using saliva. → 0.5 pt
- Humans are able to taste sweetness because of the signals that are sent to our brain that sense sweetness. → 0.5 pt
- Our taste buds detect it. → 0 pt
- We taste sweetness with a certain section of our tongue. → 0 pt

4. Why doesn't sugar cause a sour taste in your mouth?

1 pt – sugar molecules don't match with (or can't fit into) sour receptors

0.5 pt – mentions about the molecular structure or chemicals in sugar OR that sugar does not have any sour chemicals in it

0 pt – because sugar is sweet

Examples:

- Sugar has different substances that aren't in something that is sour. Our taste buds can help us recognize the difference. → 0.5 pt
- Partly because of chemicals in sugar and partly because your tongue and brain receive it as sweet. → 0.5 pt
- Sugar has a specific molecular structure which makes it taste sweet. → 0.5 pt
- There are different taste buds in your mouth that tastes different taste in the tongue. → 0 pt

Questions 5 – 10: Test of Domain Knowledge

5. What do you think a molecule is?

1 pt – the smallest piece of a substance that has properties of that substance OR one or more atoms bonded together
The answer should reflect an accurate academic understanding of a molecule.

0.5 pt – a small particle (any correct statement about it being small AND it being part of matter, substances, or things)
The answer should include some terminology that indicates chemistry knowledge (atom, particle, matter, chemical, etc.).

Examples of 1 pt answers:

- A molecule is an atom or combination of atoms used to make elements.

Examples of 0.5 pt answers:

- A particle that makes up matter.
- Something small that makes you up, but not as small as an atom.
- A molecule is made up of particles. Molecules help form things.
- It's like an atom

Examples of 0 pt answers:

- It what makes up everything
- A molecule is something that makes up a cell.
- It's a part of your body. Really small.
- Some small living thing

6. What is a cell?

1 pt – the smallest functional unit or basic building block of a living organism
The answer should demonstrate some sense of learned knowledge and (1) the concept of being small and (2) being a functional unit of living things.

0.5 pt – Answer that demonstrates either the concept of being small and part of an organisms OR being a functional unit of an organism; OR demonstrates some sort of school learning (i.e., a cell holds DNA)

0.25 pt – any correct factual statement about a cell that is not a definition

Examples of 1 pt answers:

- A cell is a small structure in our bodies that complete different functions. A cell can build tissues that build organelles to organs, to organ systems. This is the basic building structure of an organism.
- A cell is something that lives in a living organism/human body. It supports us with functioning and everyday life. They also contribute to the processes that happen everyday in our body.
- A cell is a living organism that produces more cells.

Examples of 0.5 pt answers:

- A cell is a particle in living things.
- It's an organism.

Examples of 0.25 pt answers:

- A cell is in your body.
- The smallest unit.

Examples of 0 pt answers:

- A group of items in your body combine.
- A cell is a building block of almost every thing known to man.
- A cell is small atoms in your body.

7. Which is bigger, a molecule or a cell?

1 pt – a cell

8. What do you think a receptor is?

1 pt – something that receives or attaches to something

0.5 pt – a true statement about receptors, but not the definition

Examples:

- Something that takes things in. → 1 pt
- A receptor is something that takes in an external source and gives reaction to it. → 1 pt

- A receptor is something that senses something. For instance, in the body: cell receptors let in glucose. The cell receptors sense the insulin that signaled them. → 0.5 pt
- A receptor is a part of the tongue that helps distinguish a taste → 0.5 pt

9. What do you think the word "conform means" means? If you can, provide an example of something that conforms to your hand.

1 pt – something that fits the shape of/molds to/ complements the shape of something in order to fit or match
0.5 pt – if the student only provides an example, such as glove, playdough, or joystick
OR, if defines conform as a direct verb (to make something change its shape)

Examples:

- To put in a certain position. → 0.5 pt
- To change in form → 0.5 pt

10. In science class, you may have heard the phrase "structure affects function." What does that mean? Can you provide an example?

1 pt – The way that something is shaped (or the physical shape or design) affects how it works. For example, the folded shape of the small intestine helps it to absorb more food. (Answer demonstrates full understanding—usually through an example)
0.5 pt – The way that something is made affects how it works. (The answer doesn't clearly communicate the importance of the physical shape, OR the example provided doesn't demonstrate full understanding.)

Examples:

- Structure affects function means that having a certain amount and percentage of materials makes something work. An example of this is a car. Cars have several parts which makes it work in a safe way. Remove part of the structure and no longer is it a good condition machine, with mediocre or no function. → 1 pt [understands that the parts making up something affects how it works]
- How something is made can affect what it can do. → 0.5 pt
- How your body is structured or formed is how the function will perform. For ex: half your arm, half your arm functions will work. → 0.5 pt
- The way you structure something it can affect the way it works. → 0 pt [b/c rewriting the statement]

Appendix E

Free Recall Rubric – List of Idea Units

Notes:
a. Phrases in parentheses have either already been accounted for, or are unnecessary for the gist level meaning of the idea unit. That is, it is all right if these phrases are omitted when scoring students' recalls.
b. Phrases in braces are examples of acceptable responses/equivalent idea units
c. Underlined words or phrases are key words or phrases found within an idea unit and should be scored as a separate idea.
d. An asterisk indicates an inferred idea from the text that often appeared in student recalls.
e. Phrases in italics are partially correct idea units that receive partial credit

Paragraph 1

1. Who doesn't love sweets? / {everyone loves sweets}
2. (From a creamy) ice cream (cone to a ripe) banana / {either example can be used}
3. all love (yummy, sweet) taste / {everyone loves taste of sweets; sweets taste wonderful}
4. (But) how (do we sense) sweetness? / {How do we taste sweetness? How do we taste sweet?}

Paragraph 2

5. A lot happens /{there's a lot involved in the process of tasting}
6. on (your) tongue
7. when (you) eat (a sweet ripe banana) / {when you eat something sweet}
8. banana
9. As (you) chew
10. (your) saliva
11. breaks down (the fruit) /{food is broken down}
12. into (separate) molecules
13. (The molecules) float into (your) taste buds /{food/molecules enter taste buds}
14. taste bud
15. (which sit) on (the little) bumps / {taste buds are on the bumps} /
    {taste buds are the bumps → give 0.5 credit}
16. (you can see) on (your) tongue
17. (Under a) microscope / {when you zoom in close}
18. (a taste bud) looks like an onion /
    {a receptor looks like an onion → 0.5 credit}
19. with a (small) opening
20. at the top
21. Inside the taste bud (are taste cells)/ {taste buds have taste cells}
22. taste cells
23. which contain (different kinds of) receptors
24. receptors
25. (Receptors are) structures that receive (specific substances) / *{if just mentions "structure" → 0.5 credit}*
26. and attach to specific substances / {attach to specific things}
27. When a food (molecule from the banana) drops into the taste bud / [repeated idea unit]
28. {it attaches to a receptor}/{Give only 0.5 for this idea unit since it is an inference drawn from 29}
29. it fits into its matching receptor / {molecules fit/conform/match the shape of the receptor} / *{it fits into its matching taste bud → 0.5 credit}*
30. like a key into a lock
31. This starts a process that sends a signal / {a message is sent}

32. (to the) brain
33. (which then) tells you (there is) something sweet (on your tongue)

Paragraph 3

34. Your mouth contains (10,000) taste buds / {we have many taste buds}
35. (about) 10,000 / *{1,000 → 0.5 credit}*
36. Each (taste bud) has receptors for all (five) tastes
37. five (tastes) / {there are five tastes}*
38. sweet
39. sour
40. bitter
41. salty
42. (and something called) umami
43. pronounced oo-MOM-ee
44. (the taste of umami was) identified by a Japanese scientist
45. (it is the) savory or yummy taste / {either description is fine}
46. (that we find) in foods like meat broth or cheese / {either example is fine}
47. (Most) foods spark reactions in more than one kind of receptor / {most foods have more than one taste; different foods have different taste molecules}/ {most food have more than one taste bud that they fit into → 0.5 credit}
48. (For example,) a tomato (has molecules of) / {a tomato has different molecules of}
49. sweetness
50. sourness
51. saltiness
52. and umami.
53. As (the tomato) ripens / {over time}
54. the balance changes
55. (There is) less sour / [“less” needs to be correct to receive credit]
56. more sweet / [“more” needs to be correct]
57. and more umami [“more” needs to be correct]

Paragraph 4

58. (A banana) has several different kinds of sugar/ {there are different kinds of sugar}
59. All (of these different sugar molecules) fit (neatly) into the sweet receptors (on your tongue)
60. (A sugar molecule will fit in a sweet receptor), but not in a sour or bitter receptor
61. (This is) because (sweet, salty, sour, bitter, and umami) receptors each have their own shape / {each receptor has a different shape}
62. for a molecule to fit (into the receptor)
63. it has to conform to that shape / {a molecule will fit into the receptor if it has the right shape OR the taste has to match the shape of the receptor OR it fits based on the shape – give 1 credit for 62 and 63 each}; *{a molecule will fit into a receptor if it has the same size → 1 credit for 62 and 0.5 credit for 63}*

Paragraph 5

64. Our understanding of taste has advanced (rapidly) / {We have learned a lot, scientists have learned}
65. (in the last) ten years / {this past decade}/ *{in recent history → 0.5 credit}*
66. One breakthrough was the discovery / {an important discovery was that; research shows}
67. (that sweet) receptors (in mammals) combine two (proteins)/ {sweet receptors have two parts}/ *[give 0.5 credit if it is not clear that the sweet receptor is made of two parts e.g., “mammals have 2 proteins that allow them to taste sweetness”] /{mammals have 2 main receptors → 0.5 credit}*
68. (sweet receptors) in mammals

69. <u>proteins</u>
70. (labeled) T1R2
71. T1R3
72. If either part is missing,
73. the receptor won't respond (to sweet molecules)/ {"you need both parts to taste sweetness" – give credit for 72 and 73}
74. For example, cats don't have (the T1R2 protein)/ {cats don't have one part}/ {cats don't have a receptor → 0.5 credit}
75. (the) <u>T1R2</u> (protein)
76. and so they have no interest in sweet foods / {they don't eat sweet foods}

Extra inferences

77. {Each receptor detects or distinguishes a different kind of taste} / {There is a specific receptor for each taste molecule} [inferred from idea unit 61]
78. {Each taste has a different shape} [inferred from idea unit 61]
79. {This article is about how we are able to taste food/ taste different types of tastes} [inferred from idea unit 4]

Notes on the rubric

1. Number 8 (banana) might seem insignificant. But I would like to note how many times students recall accessible or familiar terms in the reading.

Notes when scoring

1. If students misspell T1R2 and T1R3 by 2 letters or more, then give ½ credit (e.g., R1C2, R1C3 or TI1, TI2)
2. If students mention T1R2 and T1R3, do they get credit for idea unit 67? No, idea unit 67 refers to sweet receptors in mammals having two parts.
3. Give full credit for anything resembling umami (e.g., unaumi, ummie, umao…).
4. Give credit for the presence of an underlined term, even if it is not used correctly.
5. The first mention of the term "taste bud" should be scored as idea unit 14. Only give credit for 34 if it mentions that our *mouth* contains taste buds.
6. Give only 0.5 pt for idea unit 28 because it is an inference based on idea unit 29.
7. "You need a protein that allows you to detect the flavor of sweetness." (give credit for idea units 69, 72, and 73)
8. "Taste buds contain receptors" (give credit for taste buds, contain receptors, and receptors—idea units 14, 23, and 24)

Appendix F

Guidelines Used to Develop the Free Recall Rubric

Free recalls have been used extensively in reading comprehension research. They can be scored in a number of different ways, depending on what is salient in the text. For example, they can be scored mechanically by counting the total number of content words (e.g., nouns, verbs, adjectives, etc). The problem with this method is that when counting single words apart from context, one can't be certain of how much meaning the student has retained from the text. Students can write incorrect statements using words present in the text, and the ideas would be scored as present even though the underlying idea is not. Moreover, students may write inferences in their recall that are not explicit in the text, but not receive credit for those ideas.

I wanted to produce a rubric for the free recall that would capture both the explicit content (recalled words) as well as the underlying ideas in the text. Ultimately, I adapted the methods of Meyer (1985) and Mayer (1985) found in the book *Understanding Expository Text: A Theoretical and Practical Handbook for Analyzing Explanatory Text* (Britton & Black, Eds., 1985) to analyze the text and create a rubric. I also drew upon ideas from Chambliss (2002). Meyer's method of analyzing expository text is rigorous and systematic. She analyzes the rhetorical function of different portions of the text (e.g., is it meant to describe something, compare and contrast, etc.) and parses it to the word level. Mayer's system is a little more arbitrary, but captures the meaning of sentences in the text by using a larger grain-size of analysis.

Meyer's Method

Meyer analyzes text according to its propositional text structure and creates a hierarchy of ideas that is meant to capture "the underlying logic and message of the text from the perspective of the author" (Meyer, 1985, p. 15). Part of her process involves identifying the top-level ideas, or *macropropositions,* and identifying the logical or rhetorical relationships among them. Meyer relies on five categories of relationships among ideas that can be found in text: collection, cause-effect, response (also question/answer or problem/solution), comparison, and description. The "collection" relationship includes "ideas or events [that] are related together into a group on the basis of some commonality" (Meyer, 1985, p. 17). This category also includes sequences or processes. Once the top-level text structures are identified, Meyer then analyzes the text down to the word level, while simultaneously identifying the function of the different phrases or words.

Here is one example of a how a text is analyzed according to Meyer's method. The excerpt appeared in *Understanding Expository Text* and was slightly modified for the purposes of this example:

> One problem is how to prevent oil spills from supertankers. Oil spills kill microscopic plant life which provide food for sea life and produce 70% of the world's oxygen supply.
>
> The solution to the problem is not to halt the use of tankers since they carry about 80% of the world's oil supply. Instead the solution lies in the following three tactics. First officers of the supertankers must be trained in how to run and maneuver their ship. (modified from Meyer, 1985, pp. 283-284)

Meyer analyzed the supertanker passage in the following manner:

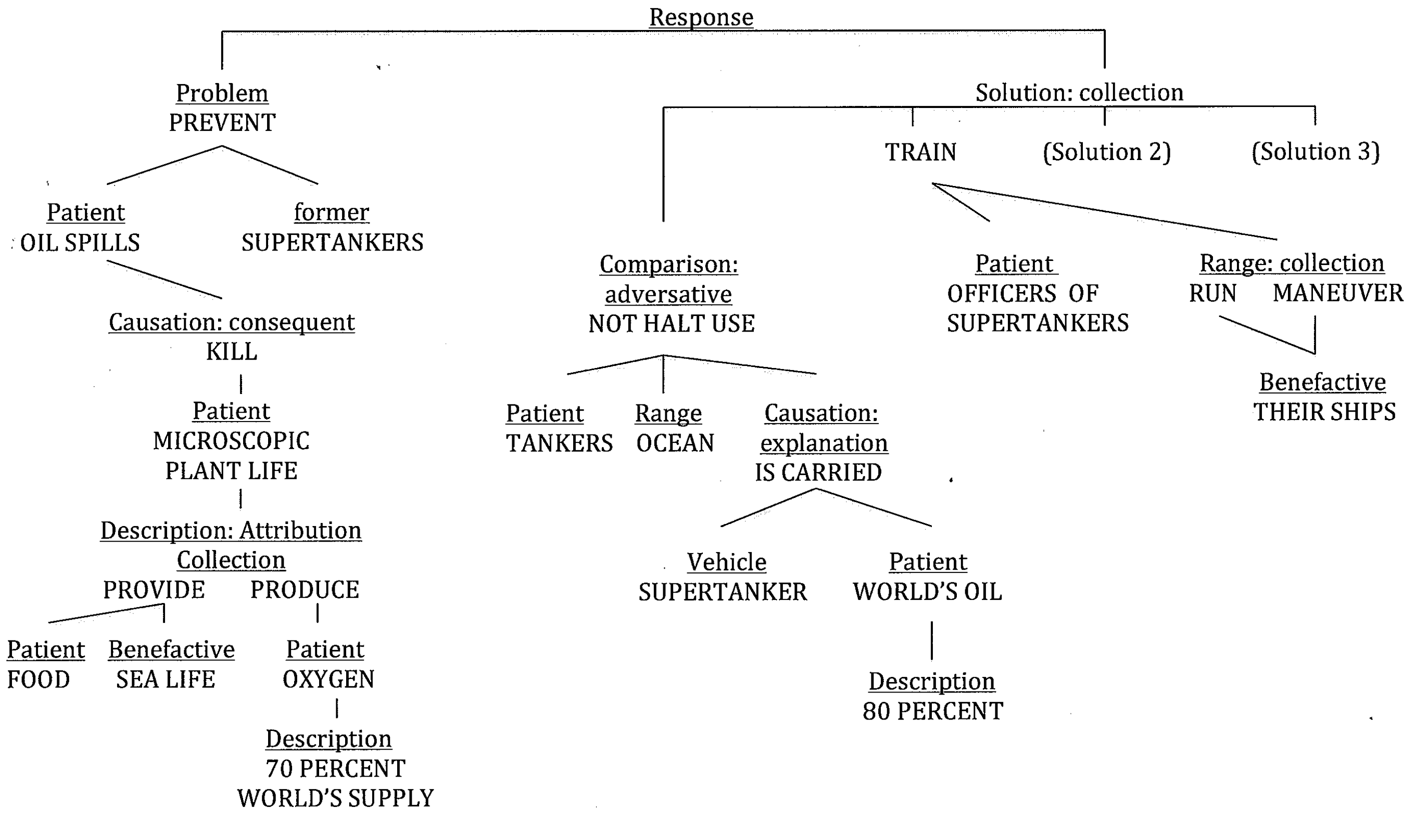

Figure A1. Meyer's analysis of the "Supertanker" text (adapted from Meyer, 1985, pp. 285-287)

Mayer's Method

In contrast, Mayer uses a larger unit of analysis called the "idea unit". He defined it in the following manner:

> An idea unit expresses one action or event or state, and generally corresponds to a single verb clause….Thus, each idea unit consists of a predicate[1]—either a verb or a location or a time marker—and one or more arguments [direct object, indirect object, and sometimes prepositional phrases]…. For example, consider the sentence: 'It creates concentric circles of small waves that continue to grow outward.' The two main verbs are located: "creates" and "grow." Thus, this sentence is divided into two idea units:
>
> 1. It *creates* concentric *circles* of small waves
> 2. that continue to *grow* outward." (Mayer, 1985, p. 71)

The key words in each idea unit, which are essential to the gist meaning of the phrase, are identified (using italics in this example). When scoring the recalls using Mayer's system, the student's protocol is divided into idea units, and are then compared to the rubric created from the original passage. "If the idea unit from the protocol includes the same keywords (e.g., "creates" and "circle") and expresses the same meaning as an idea unit from the original passage, that idea unit is scored as present" (Mayer, 1985, p. 71).

Mayer analyzed the same Supertanker passage that was analyzed by Meyer (see Figure A1), which resulted in the following protocol:

---

[1] A verb predicate is the part of the sentence that tells something (action or condition) about the subject. It includes the verb, objects, and clauses. (From http://grammar.about.com/od/terms/)

1. One problem is

2. how to *prevent oil spills* from *supertankers*

3. Oil spills *kill* microscopic *plant* life

4. which *provide food* for sea life

5. and *produce 70 percent* of the world's *oxygen* supply.

6. The solution to the problem is

7. *not* to *halt* the use of *tankers* on the ocean

8. since *80 percent* of the world's *oil* supply is carried by *supertankers.*

9. Instead, the solution lies in the following three tactics.

10. First

11. *officers* of the supertankers must *get* top *training*

12. in how to run and *maneuver* their ships (adapted from Mayer, 1985, pp. 308-309)

Guidelines Developed for this Study

One can compare the advantages and disadvantages of the different methods. The Meyer system of prose analysis is very comprehensive and systematic. But for my purposes, when developing the rubric for the free recall, it wouldn't help to analyze the text at such a detailed level. I also didn't need to assess students' awareness of text structures on a rigorous basis.

A disadvantage of Mayer's system is that the grain-size of analysis (his idea unit) was too large (and somewhat arbitrary, if you see his other examples). I ended up using Mayer's system, but because I wanted to be able to score a number of concrete, although relatively unimportant, details in students' recalls, I created additional rules for identifying an idea unit. Below are the final guidelines that I used for parsing the experimental text.

A separate idea unit is created for:

1. a verb predicate (which includes the verb, and object(s) necessary for the main idea of the sentence), as well as the subject if present.

2. Any adjunct phrase that is *not* necessary to complete the verb and that is *not* necessary for the main idea of the sentence. These were often adverbial or prepositional phrases that indicated time, location, or manner (e.g., “in the last 10 years”, “under a microscope”, “into separate molecules”).

At times, there are phrases that are not necessary to complete the verb, but that are necessary for the main idea of the sentence. For example: “Each [taste bud] has receptors for all five tastes.” I kept this as a single idea unit, instead of breaking it into two “Each [taste bud] has receptors / for all five tastes” because having *all five* receptors rather than “having the receptors” was the main point of the sentence. Also, the idea that taste buds have receptors was previously established.

3. Specific terminology or details of interest that were not already marked off as a separate idea unit (e.g., saliva, 10,000, mammals, T1R2). This rule gives more latitude to the researcher to identify ideas that are of interest or salient to the study/analysis. (In my case, I was interested in the recall of scientific terms, as well as other familiar, concrete details.)

Here is an example of a sentence that was divided into idea units using Rules 1 – 3:

“As you chew, your saliva breaks down the fruit into separate molecules.”

Per rule 1, there are two verbs, “chew” and “breaks down.” The passage would be divided as follows:

“As you chew / your saliva breaks down the fruit into separate molecules.”

Per rule 2, there is one prepositional phrase that is not necessary to complete the verb.

Thus the idea units are as follows:

“As you chew / your saliva breaks down the fruit / into separate molecules”

Per rule 3, although saliva is not necessary to the gist-meaning of the sentence, I wanted to identify the recall of the science term “saliva.” So, that was made into its own separate idea unit (marked by an underline.)

“As you chew / your <u>saliva</u> breaks down the fruit / into separate molecules.”

Thus, there are four idea units in total. The gist-meaning of the second idea unit is that the fruit is broken down. Thus, when grading the protocols, the student would receive credit for any equivalent statement, and receive separate credit if they included the term “saliva.”

4. Even though they don’t have individual verbs, a collection of terms was divided into separate idea units, since they are separate conceptual units.

Example: “Each one has receptors for all five tastes: sweet, sour, bitter, salty, and umami.”

“…for all five tastes / sweet / sour / bitter / salty / and umami.”

One could also view the sentence as “there is sweet, there is sour, there is salty, etc.”

5. Repeated idea units were not included.

For example, the idea that tasting occurs on the tongue was repeated a couple of times. So it was only included once as an idea unit. It appeared in the sentence “A lot happens on your tongue”, and thus, was not counted as a separate idea unit in the later sentence: “...which then tells you there is something sweet on your tongue.”

“…which then tells you / there is something sweet on your tongue.”

6. When grading student protocols, there were sometimes inferred ideas, i.e., ideas not explicit in the text, which many students expressed in their recall. These ideas could be directly

inferred from specific segments of the text and were also included in the rubric. For example, "[a molecule] fits into its matching receptor like a key into a lock." Some students mentioned that the food attaches to the receptor, without really communicating the sense of fitting/matching/conforming. The idea of "attaching" can be inferred from the text and from the word fitting, so I included it as a separate idea unit in the rubric.

7. Lastly, there were some major inferences that could be clearly drawn from the reading, but which spanned distant portions of the text and or which didn't align directly with the idea units in the text. One example is that "each receptor detects a different taste." Another was that "each taste molecule has its own shape." Both of these inferences could be inferred from the content of paragraph 4. In order to be able to score the presence of these important inferences, these idea units were included at the end of the recall rubric.

Using these guidelines, the text *Sense of Sweet* was analyzed and broken down into 76 idea units for the recall rubric. The text analysis and rubric can be found in Appendix E. When scoring, student protocols were examined for idea units that matched—or which provided the substantive gist of—the idea units in the rubric.

Appendix G

Main Ideas Rubric

* Ideas in braces are not explicitly stated, but must be inferred from the text.
** Phrases in parentheses have already been included somewhere else in the rubric

Segment of Text and Purpose	Main Ideas	Important Details	Less Important Details	Least Important Details
Paragraph 1 **Introduction:** To generate interest, present the topic, and pose the over-arching question				1. Who doesn't love sweets? 2. From a creamy ice cream cone to a ripe banana 3. We all love that yummy sweet taste
	4. But how do we sense sweetness?			
Paragraph 2 **Main explanation:** - *Description* of overall process of tasting sweet (sequence)	5. A lot happens {in the process of tasting}			6. on your tongue 7. when you eat a sweet ripe (banana) 8. banana
				9. As you chew
	11. (your saliva) breaks down the fruit / {food is broken down}		10. your saliva	
		12. into separate molecules		
	13. (The sweet molecules) float into your (taste buds) / {food enters your taste buds} 13b. taste buds			14. {taste buds} sit on the little bumps 15. on your tongue 16. Under a microscope 17. (a taste bud) looks like an onion 18. with small opening 19. at the top
		20. Inside the taste buds are taste cells 21. taste cells 22. {Taste cells} contain different kinds of receptors		

	27. (it) [attaches to and] 28. fits into its matching receptor 30. This starts a process that sends a signal 32. which tells you there is something sweet on your tongue	23. receptors 29. like a key into lock	24. Receptors are structures that receive 25. and attach to specific substances 31. to the brain	26. When a food molecule from a banana drops into the taste bud
Paragraph 3 Subexplanation: How foods trigger a variety of taste receptors - *Description* of different kinds of receptors (and tastes) - *Description* of how foods trigger a variety of taste receptors	35. Each (taste bud) has receptors for all (five) tastes 46. Most foods spark reactions in more than one kind of receptor / {most foods have more than one kind of taste molecule or more than one taste}	33. Your mouth contains (about 10,000) taste buds 37. sweet 38. sour 39. bitter 40. salty 41. and something called umami	44. {Umami} is the savory or yummy taste 47. For example, a tomato has molecules of	34. about 10,000 36. five 42. promounced oo-MOM-ee 43. The taste of umami was identified by a Japanese scientist 45. that we find in foods like meat broth or cheese 48. sweetness 49. sourness 50. saltiness 51. and umami

			52. As (the tomato) ripens 53. the balance changes / {the balance of the taste molecules can change}	54. There is less sour 55. more sweet 56. and more umami
Paragraph 4 Subexplanation: How sugar molecules trigger a sweet taste (and not other tastes) - *Explanation* of why sugar molecules combine with sweet receptors and not other receptors	58. All (of these different) sugar molecules fit neatly into sweet receptors 59. (A sugar molecule will fit in a sweet receptor), but not in a sour or bitter receptor	60. This is because sweet, salty, sour, bitter and umami receptors each have their own shape / {each taste has a different shape} 61. For a molecule to fit into the receptor 62. it has to conform to that shape / {a molecule will fit into the receptor if it has the right shape}	57. A banana has several different kinds of sugar / {there are different kinds of sugar molecules}	
Paragraph 5 Subdescription: Elaboration of the structure of sweet receptors and how it affects their function *Description* of sweet receptors having two parts and *explanation* of how	66. (that) sweet receptors (in mammals) combine two (proteins) / {sweet receptors	63. Our understanding of taste has advanced rapidly	65. One breakthrough was the discovery 67. (receptors) in mammals	64. in the last ten years

this affects their function	have 2 parts} 71. If either part is missing, 72. the receptor won’t respond to sweet molecules / {need both parts of the receptor to taste sweetness}		68. (combine two) proteins 73. For example, cats don’t have{one part of the sweet receptor} 75. and so they have no interest in sweet foods	69. labeled T1R2 70. and T1R3 74. T1R2

Based on method by Mayer (1985) and Meyer (1985); and Chambliss (2002)

Appendix H

Guidelines Used to Establish the Main Ideas Rubric

To develop the main ideas rubric, I re-analyzed the text using several different frameworks, particularly that of Meyer (1985) and Chambliss (2002). A rough hierarchy of ideas was created using Meyer's text structure system. First, I identified the logical /rhetorical relationship among ideas. These relationships can generally be categorized as collection, cause-effect, response (question-answer or problem-solution), comparison, and description. I then created a hierarchy that was meant to reflect the meaning and author's intent in writing the text. A critical step in this text analysis was to identify the top-level structure of the text, i.e., "The relationship that can subsume the greatest amount of text" (Meyer, 1985, p. 22). For the text used in this study, the top-level structure was a question-response. The question was explicitly stated in the first paragraph "How do we sense sweetness?" and the remaining four paragraphs were devoted to answering that question.

When creating the hierarchy of ideas, I also used Chambliss's framework (2002) for describing explanations. The overall text was an explanation of how we taste sweetness. According to Chambliss, an explanation consists of subexplanations (information, examples, analogies or models) in "a logical order to form a bridge between the reader's current understanding and the new understanding" (Chambliss, 2002, p. 58). The subexplanations in the text were identified: paragraph 2 described the overall process/sequence of tasting, paragraph 3 described how foods are able to trigger a variety of taste receptors, paragraph 4 explained how and why sugar molecules trigger a sweet taste and not other tastes, and paragraph 5 elaborated on the structure of sweet receptors, and how it affects the ability to taste sweetness. This overall framework for the explanation was used in conjunction with Meyer's categories of relationships to categorize the importance of the different propositions (or idea units) of the text.

To use paragraph 2 as an example, its main purpose is to describe the overall process of tasting sweetness. Using Meyer's framework, the main propositions are a sequence (a collection) of steps that can be described roughly as the following: 1. saliva breaks down the fruit into separate molecules, 2. the (sugar) molecules float into the taste buds, 3. the molecule fits into its matching taste receptor, and 4. a signal is sent that says there is something sweet on your tongue. These would fall on the same level of the hierarchy. Other portions of the paragraph provide supporting details, which would be placed lower in the hierarchy (e.g., the description of the structure and location of the taste buds, or a general definition of a receptor).

Meyer's hierarchical analysis can accommodate both a small-grain size (down to the word level) and larger grain-sizes (phrases or predicate). I used the idea units created for the purpose of the recall rubric as the grain size. For step 1 "the saliva breaks down the fruit into separate molecules," the verb predicate "breaks down the fruit" is the core of the sentence and is listed high on the hierarchy. The agent "saliva" and the description "into separate molecules" are placed at a lower level in the hierarchy depending on their judged relative importance to the text. In this case, the fact that saliva breaks down the food is not essential to understanding the overall explanation. However, the concept of molecules is more important to the understanding of how they attach to receptors, so it was placed higher than saliva.

Using this process, the idea units were placed into four categories of importance: main ideas, important details, less important details, and least important details. When scoring the recalls for the presence of important ideas, any idea unit from the first two categories (main ideas and important details) was counted as a Main Idea. Any idea from the latter two categories (less and least important ideas), was counted as a Less Essential Idea.

To ensure its validity, the main ideas rubric was reviewed by two reviewers. One was a graduate student at Teachers College working in the field of literacy and text structure, and the other a high school science teacher with 10 years of teaching experience. The science teacher was able to evaluate whether the hierarchy of idea units also reflected the instructional importance of the idea units relative to the topic of tasting sweetness.

The complete hierarchy of ideas that was created using this general method is shown in the figure below.

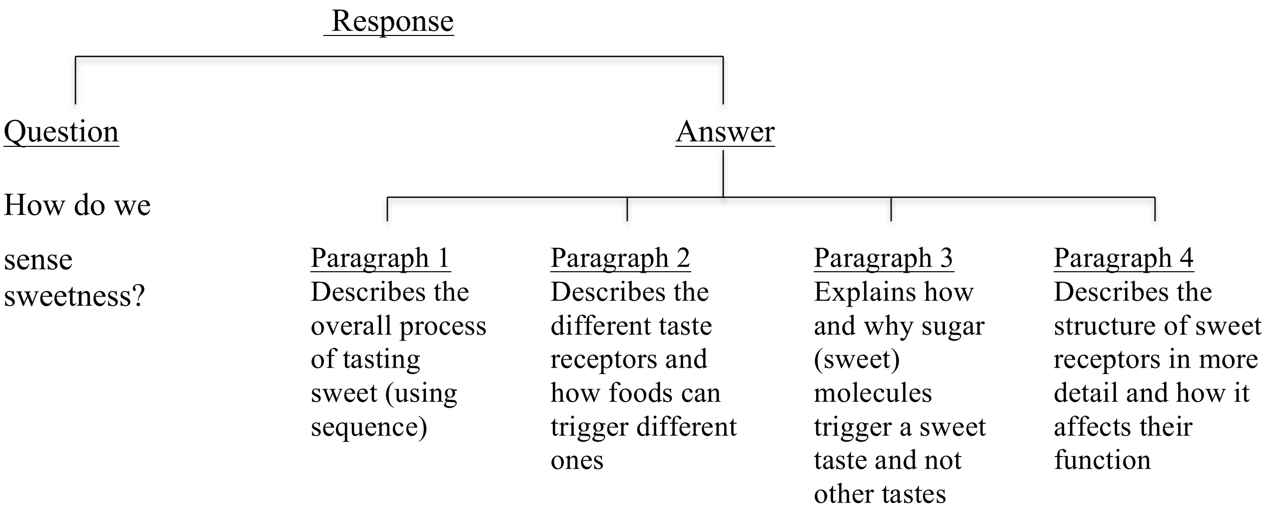

Figure A2. Overview of the hierarchical structure of the “Sense of Sweet” passage

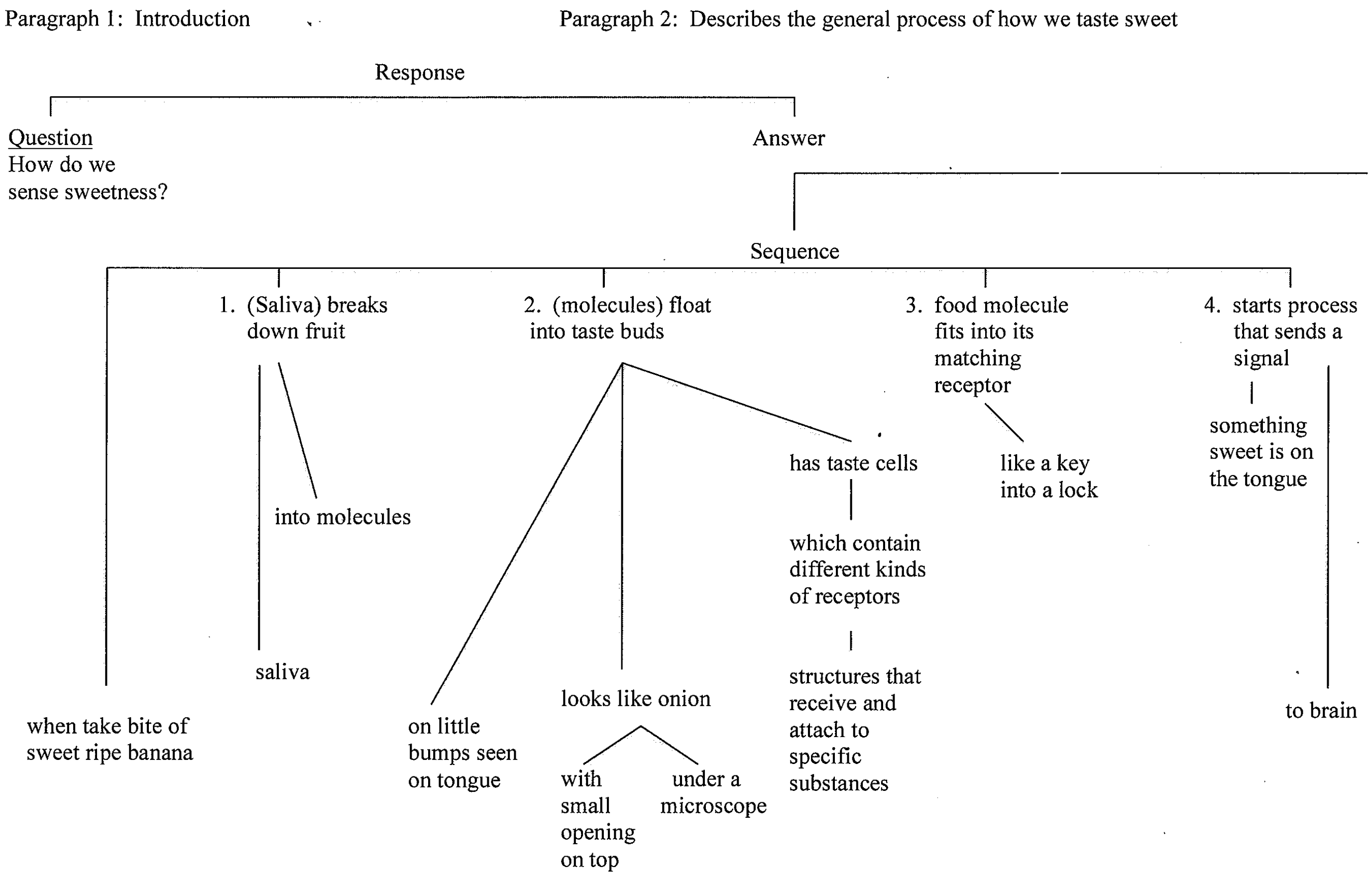

Figure A3. Hierarchical analysis of the “Sense of Sweet” passage, paragraphs 1 and 2

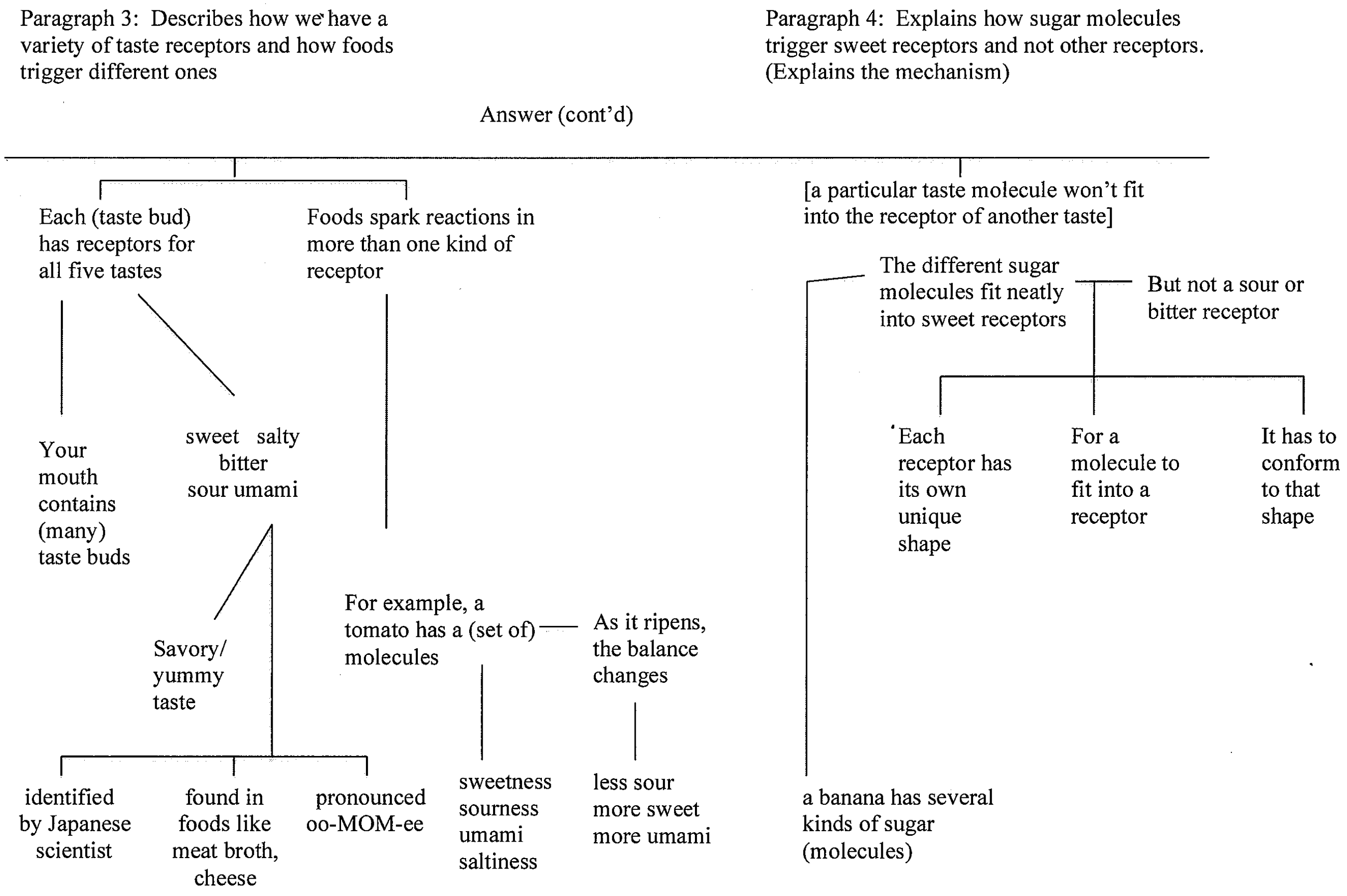

Figure A4. Hierarchical analysis of the "Sense of Sweet" passage, paragraphs 3 and 4

Paragraph 5: Describes the structure of sweet receptors in more detail and how it affects their function

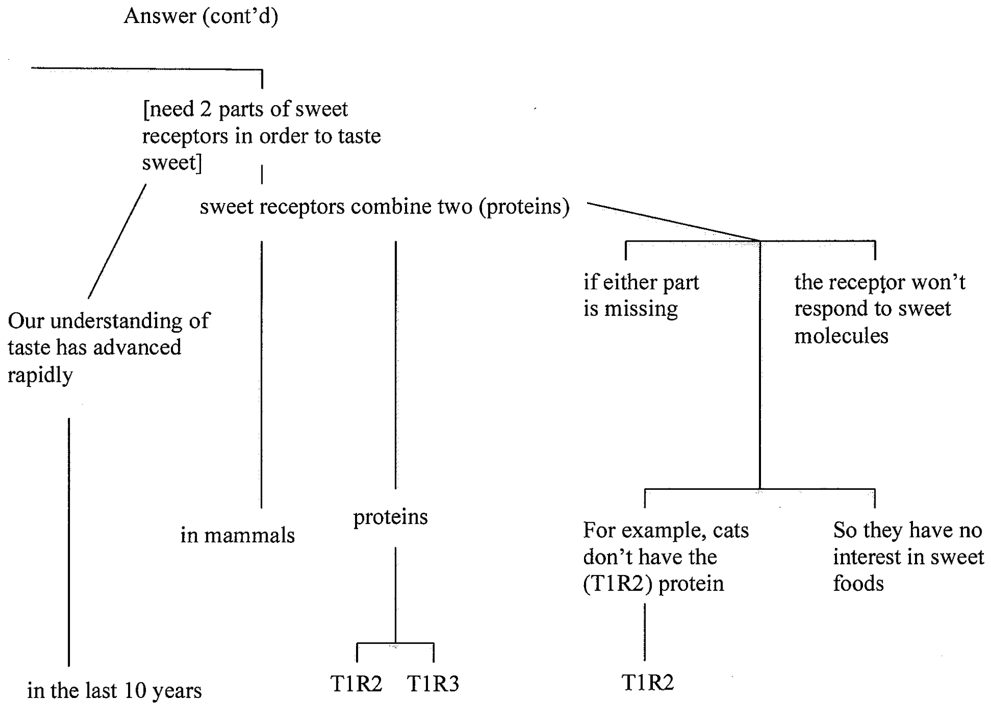

Figure A5. Hierarchical analysis of the "Sense of Sweet" passage, paragraph 5

Appendix I

Holistic Rubric for Recall

Category	Criteria – completeness (i.e., does it include important points?), coherence and organization of ideas, degree of accuracy, elaborateness	Example
Level 4.5 Complete Explanation, Elaborated	KEY FEATURE: Demonstrates a complete and sophisticated understanding of the process involved in sensing sweet, including how taste molecules fit the shape of the receptor. Also includes elaborated information about supporting concepts. - Meets the criteria described in Complete Explanation, Simple PLUS - Demonstrates understanding of any of the following elaborations: 1) The broader context of tasting sweet. Taste buds contain receptors for all five tastes, including umami. Foods often have more than one kind of taste molecule. Can include the example of the tomato. 2) The necessity of both parts of the sweet receptor for it to function. Sweet receptors are actually made of two parts (proteins), and both are needed for the receptor to function properly. May include the example of the cat. - Information is accurate, may contain one minor misconception*	When we eat something, the saliva comes in and starts to break the food down into molecules. Then our taste buds will absorb the molecules. In the taste buds, there are many receptors. Each receptor “detects” a kind of taste. There are 5 different tastes: sweet, bitter, salty, unami, and sour. Each of molecules have a different shape that indicate a taste. The receptor has a space in them like a mold so only the molecules with the correct shape can fit into them. When a molecule reach into a taste bud, the taste bud will send a message of what the food is taste like. Recent research shows that only mammals with T1R2 and T1R3 have interest in sweetness. So cats which don’t have T1R2, have no interest with sweetness. Fun fact: From naked eye, the taste buds look like bumps, but in a microscope the taste buds look like onions. (12)
Level 4 Complete Explanation, Simple	KEY FEATURE: Demonstrates a complete understanding of the process of tasting sweet, including how taste molecules match the shape of the receptor. - Includes all the key steps in the process **1. Food is broken down (by saliva) (into separate molecules) and enters taste buds** **2. The food fits into matching receptor (in taste cells/ in taste buds)** **3. Receptor sends a signal/message (to the brain) that there is something sweet**	There are many things I learned in this article. One thing I learned is how you know that what you are tasting is sweet. First your saliva breaks up the food into small molecules. Then the molecules go into your taste bud which is those bumpy things on your tongue. If what you are eating is sweet it will fit into your sweet receptor. Then when it goes in it send a signal to your brain that tells you what you are eating is sweet. This works with all 5 tastes: sweet, bitter, umami, etc. Each receptor for the different tastes are shaped different so depending on which receptor the molecule fits into you can have your brain tell what type of taste the food is. (34)

	- AND demonstrates understanding of complementarity. (I.e., Food molecules have to attach and match the shape of, or fit, the receptor in order to cause that particular sense of taste.) - Organizes ideas in a way that is coherent and that reflects an explanation (i.e., provides an explanatory overview sentence or includes terms in a way that signifies or implies causality, such as because of, then, etc.) - Most of the information is accurate; may contain one minor misconception	From this article, I have learned how we taste things. There are different tastes like sweet, sour, bitter, salty, and umami (sweet/savory). First we eat the food, for example a fruit, and it's broken down by our teeth and saliva into molecules. Those molecules then fit into different receptors on our tongues. There are individual receptors for each taste. In the end, the receptors send signals to the brain and tell it the taste. (62)
Level 3.5 Partial Explanation, Elaborated	KEY FEATURE: Demonstrates partial understanding of the process involved in sensing sweet, including the involvement of the receptors, and includes more elaborated information about the supporting concepts. - Meets the criteria for Partial Explanation, Simple PLUS - Demonstrates understanding of any of the following elaborations: 1) The broader context of tasting sweet. Taste buds contain receptors for all five tastes, including umami. Foods often have more than one kind of taste molecule. Can include the example of the tomato. 2) The necessity of both parts of the sweet receptor for it to function. Sweet receptors are actually made of two parts (proteins), and both are needed for the receptor to function properly. May include the example of the cat. - Information is accurate; may contain one minor misconception	The article was about how taste buds taste a sweet flavor from foods. It includes facts such as the tongue has 10,000 taste buds. They have receptors for sweet, sour, bitter, salty, and unami flavors. The unami flavor for the taste bud receptor was discovered by a Japanese scientist. When you eat a food, your saliva combines with it, then the taste from the food goes onto your taste bud. Next the taste goes to the taste receptor which determines which of the 5 flavors does it taste like. When finished it sends a response to the brain about what you are eating. Scientists have learned that many mammals can taste due to 2 proteins TI1 and TI2. Without one of the proteins, mammals can not taste sweet foods. This is why cats are not able to taste sweet foods. (35)
Level 3 Partial Explanation, Simple	KEY FEATURE: Demonstrates a partial understanding of the process involved in sensing sweet, including the involvement of the receptors. - Includes most steps of the process: **1. Food is broken down (by saliva) (into separate molecules) and enters taste buds** **2. The food attaches to a receptor (in taste cells/ in taste buds)** **3. Receptor sends a signal/message (to the brain) that there is something sweet**	I remember that you're taste buds are like little onions with small openings on the top. On the top is a receptor that separates the taste of food such as sweet, salty….And when you eat your food it separates it into different receptors based on the taste. Also we have 10,000 taste buds in our tongue. The different tastes are like a key to a door which means a new taste goes in a receptor. (56)

	- Demonstrates understanding that sugar molecules attach to a sweet receptor BUT makes no mention of the molecule and receptor fitting together (i.e., does not demonstrate understanding of how molecules are distinguished by shape) - Organizes ideas in a way that is coherent and that reflects an explanation (i.e., provides an explanatory overview sentence or includes terms in a way that signifies or implies causality, such as because of, then, etc.) - Most of the information is accurate; may contain one minor misconception	
Level 2.5 Rudimentary Explanation, Elaborated	KEY FEATURES: Attempts to explain how we taste sweetness and demonstrates a rudimentary understanding of the process involved in sensing sweet. Includes elaborated information about supporting concepts. - Meets the criteria for Basic Explanation, Simple PLUS - Includes elaboration of information related to important structures or examples. E.g., details about taste buds, the five tastes and umami; example of the tomato having different taste molecules; T1R2/T1R3, or explaining why cats aren't interested in sweet foods - Might mention the term *receptors*, but doesn't clearly explain that receptors receive, attach to, or fit with the food molecules. - Information is accurate; may contain one minor misconception	We can identify different tastes due to receptors in our taste buds. These help us to taste sweet, sour, salty, bitter, and umami. We have over 10,000 taste buds to help us taste. Animals have the ability to taste as well. They might not have all the tastes. For instance, cats do not have TR2 so they do not care for anything sweet. When we eat, our saliva breaks it down into molecules that travel into the onion-shape taste buds that categorize them into the different tastes we know. (1) What I learned from this article is that, when you eat a banana for instance, your saliva separates this food into tiny, different molecules. These molecules would then sit on your taste buds which allows you to taste the banana. We have 10,000 taste buds, which each have the same types of taste, sweetness, saltiness, bitterness, savory, and umami. Umami is the taste of for instance, cheese, etc. If we did not have a sort of protein on our tongue, or taste buds, we wouldn't be able to taste sweetness. In conclusion, this is as much as I remember from the article, with as much detail as possible. (53) 1) When we eat the food breaks down into molecules. 2) The molecules sit on little bumps in our tongue. 3) As the molecule is broken down it sets to be a receptor.

		4) The receptor sets off a signal to your brain which tells the different senses. 5) There are five senses in our tongue sweet, sour, salty, unami. 6) We have about 10,000 taste buds in our mouth. 7) We have two main receptors. Only mammals do. (46) [Although this mentions receptor, the phrase "sets to be a receptor" is unclear.]
Level 2 Rudimentary Explanation, Simple	KEY FEATURES: Attempts to explain how we taste sweet and demonstrates rudimentary understanding of the process involved in sensing sweet. - Includes basic or general steps of the process - BUT, does not mention receptors OR mentions receptors without clearly explaining that they attach to or fit with food molecules. - Uses terms or organizes ideas in a way that suggests an explanation - Most of the information is accurate; may contain one or two misconceptions	Today I learned that you have 10,000 taste buds on your tongue and your taste buds send signals to the brain and tell you have something sweet on your tongue. Your tongue has five senses: sweetness, saltiness, bitterness, sourness, and umami (43) I learned that how we are able to taste sweetness is by when we chew, our saliva breaks down the food which is then turned into food molecules which falls on the bumps that are on our tongues called taste buds which have receptors which signal sweet, sour, bitter, or umami which signals our taste buds what kind of taste the food has. (41)
Level 1.5 Unassociated Concepts, Elaborated	KEY FEATURE: Presents facts and concepts that are somewhat elaborated, but does not show underlying organization or relationship between the facts - Resembles a list of unassociated facts or concepts that are detailed - May include a step or steps in the process of tasting sweet, but does not organize ideas or use causal terms in a way that reflects a coherent explanation -Includes elaboration of information related to important structures or examples: e.g., details about taste buds; the five tastes and umami; the example of the tomato having different taste molecules; T1R2/T1R3; or explaining why cats aren't interested in sweet foods - Most of the information is accurate. May contain one or two misconceptions.	I learned that: -Your taste buds look like onions with small opening at the top when you are looking at them up close/zoomed in. -Each taste bud has receptors for each of the five tastes: sweet, salty, bitter, sour, and umami. -Different animals have two things for protein. If an animal does not have one of them then they do not taste sweetness. The two protein things are: T1R2 and T1R3. -Food molecules break up and then go into the taste bud's opening, into the receptor. (49)

Level 1 Unassociated Facts and Concepts, Simple	KEY FEATURES: Lists brief facts or pieces of information, and does not show underlying organization or relationship between the facts. - Includes brief facts: e.g., details about taste buds, receptors, the five tastes and umami,T1R2/T1R3, or explaining why cats aren’t interested in sweet foods - The facts that are mentioned are not directly related - May include misconceptions	I learned that we have 10,000 taste buds. Cats don’t like sweet foods. Each molecule has different receptors. Sugar will fit into the sweet receptors. Mammals have T1R2 and T1R3. We taste bitter, sweet, sour, salty, and tangy. (50) What I learned is if you don’t have RL2 on your tongue you’re not really interested in sweet foods. I also learned our taste buds have small openings. I also learned in a microscope our taste buds look like onions with tiny openings. (25)

* A minor misconception is one that relates to supporting information. A major misconception is one that relates to facts about the key structures or the process involved in tasting sweetness (e.g., if a student says that there are different types of taste buds, or that a food molecules attaches to a specific taste bud instead of to specific receptors). If a major misconception is present, the recall can be scored one level down.

For example: Protocol 6 doesn’t mention receptor, but includes all the steps: “…The molecules and the taste buds act like a key in a lock, the molecule fits into its matching taste buds and it then sends a message to your brain saying there is something sweet, sour, bitter, etc. on your tongue.” Because of the major misconception about matching taste buds, the protocol was scored as 3.0 instead of 4.0.

Appendix J

Rubric for Short-answer Performance Test

A. Explain how we are able to taste sweetness? Answer as fully as you can.

Points	Criteria	Examples
4	COMPLETE UNDERSTANDING - Describes process 1. Food is broken down (by saliva) (into separate molecules) and enters taste buds 2. The food fits into matching receptor (in taste cells/ in taste buds) 3. Receptor sends a signal/message (to the brain) that there is something sweet - AND mentions fitting or matching shape of the receptor and molecules	We are able to taste sweetness because our saliva breaks down the sweet into molecules. Then the molecules sit on our taste bus. The sugar molecule fits into the sweet receptor which sends a signal to our brain that we are eating a sweet. (30) When we eat our food, saliva comes in and breaks down the food into molecules. The molecules then go down into a taste bud. In the taste bud, there are many different receptors. The receptors are like the mold for the molecules, so some of the molecules can fit into it. If a molecule is successfully "joined" with the sweet receptors, then the receptors will give a signal to the brain saying that the food is sweet. But there is one requirement: T1R2 and T1R3. If any of them are missing, then you can't taste sweetness. (12)
3	APPROACHING UNDERSTANDING - Elaborates on the entire process and mentions sweet receptors attaching to molecules, but does not explicitly mention the fitting together of molecules or matching of shapes which distinguishes the sweet molecules	We are able to taste sweetness because on our tongue we have taste buds and if you look at them under a microscope they have a small opening and when you eat a ripe banana, your saliva breaks it down to molecules and one molecule goes onto 1 taste bud and it attaches to the sweet receptor. Then it sends a signal to your brain that something sweet entered your mouth. (29)
2	PARTIAL UNDERSTANDING[a] - Describes a part of the process; may mention receptors, but doesn't mention how receptors must match the shape of the molecule. OR - Mentions the role of the receptors (sweet receptors have a specific shape that matches the sweet molecule), but does not elaborate on the process at all. OR	We have molecules which are broken down and they sit on little bumps on our tongue and then the receptor sends a signal to the brain and it tells if it's sweet or sour. (46) Saliva breaks down what we are eating into sweetness molecules…which enter your taste buds. They then determine what that flavor is. Afterwards they send signals to the brain and inform it that what they are tasting is sweet (9) We are able to taste sweetness because of the molecules of a food that is sweet fits in with the

	- States that we have two proteins (T1R2 and T1R3) that enable us to taste sweetness. Must show understanding that missing one or both prevents us from being able to taste sweetness.	sweet receptor (1) We are able because it the fit in the sweet receptor then our tongue and brain taste it. (50) (minimum answer) We taste sweetness by having two different proteins which enable us to. We call them T1R2 and T1R3. These proteins let people taste, and missing either one or both disables us tasting sweetness. (16)
1	MINIMAL UNDERSTANDING[b] - Provides minimal information about the process that is accurate - Might mention sweet receptors, but without additional explanatory information about its role - OR mentions that we have 2 proteins (T1R2 and T1R3) that help us taste sweetness (without elaborating)	The taste buds on your tongue taste it and they signal the brain about how it tastes. (32) We are able to taste sweets because our taste buds have this thing called RL3 or TL1 which helps us taste sweets. (25) We have R1R2 or something like that. We also have R1R3. Finally we have an umami receptor. (22) We are able to taste sweetness with the sweet receptor parts of our taste buds. (17)
0	NO UNDERSTANDING -Only mentions structure that are likely known from before: e.g., taste bud, tongue, or saliva	Our taste buds have the ability to let us taste (4) We are able to taste sweet because of 10,000 buds that help us taste our food. (42) We have buds that help taste sweetness. There are also taste cells. (3)

[a] If describes both the process and the role of T1R2/T1R3 in the explanation, then give 2.5 pts,

For example: We are able to taste sweetness with our tongue. For example, when we eat a piece of candy, our saliva breaks down and separates the different molecules and then the taste buds have a small opening that will allow the molecules to go in. Then it sends a signal to your brain telling you that some part of that food is sweet. Also to let your brain get signaled, you need two types of protein, T1R2 and T1R3. If one of them is missing, it would be hard to indicate it is sweet. (48)

[b] If includes a minimal explanation and also includes the role of T1R2/T1R3 in the explanation, then give 1.5 pts.

For example: We use T1R2 and T1R3 as components to taste sweetness. We also use our taste buds to sense the taste molecules in the food and the molecules lock onto our taste buds sending messages to our brain. (10)

B. Explain how the structure of sweet receptors is important to how it works.

Points	Criteria	Examples
2	COMPLETE UNDERSTANDING - must mention that 1) sweet receptors have a distinct shape and 2) the molecule must fit into the sweet receptor shape, which enables us to sense the taste.	The structure of sweet receptors have their own shape so the sweetness will match up with the sweet receptor shape. (60) Receptors are like key holes and molecules are like keys. The molecules have to fit into the receptor for you to know if it's sweet. (6)
1	PARTIAL UNDERSTANDING - mentions one of the two details listed above. Either that receptors have a distinct shape OR that molecules must fit into the receptor in order for us to taste sweetness.	The structure of sweetness receptors is important because only sweet foods can fit into those sweet receptors. Without that structure you wouldn't taste sweetness (8) The structure of sweet receptors is important to how it works because it has to fit the food molecules in it (49)
0	NO UNDERSTANDING Does not mention anything about shape or fit.	It distinguishes the taste of one thing from another (9) It's important because we could not be able to taste certain things if the structure was different (15)

C. What was a recent and important discovery about sweet receptors in mammals?

Points	Criteria	Examples
2	COMPLETE UNDERSTANDING - Must show understanding that a sweet receptor in mammals is made of two parts, and both are needed for the sweet receptor to function - I.e., must mention that there are two proteins (or T1R2 & T1R3) that make up the sweet receptors. Without one of them you can't taste sweetness.	Mammals can taste due to 2 proteins. They are TI1 and TI2. Without one, mammals cannot taste sweet foods. (35)

1	PARTIAL UNDERSTANDING -Mentions that there are two parts (proteins, T1R2 & T1R3) to the receptors. [Only 1 pt because doesn't explicitly mention the significance of missing one.] -OR mentions that some mammals cannot taste sweetness because they are missing a part of the receptor	They have T1R2 and T1R3 (50) Some mammals don't have the protein to help taste like cats (51)
0	MISUNDERSTANDING - includes the misconception that mammals have two sweet receptors (instead of sweet receptors having two parts) - Provides the cat example (which is not the main discovery)	Certain mammals don't have sweet receptors. For example, a cat. (7) [0 points because doesn't understand that they are missing part of the sweet receptor.] If [mammals] don't have a specific receptor, they are unable to taste sweetness. (13) [Said sweet receptor instead of part of a sweet receptor.] Cats can't taste sweetness. (9) Cats don't have T12. They only have T13. (47)

D. Why does a lemon taste sour and not sweet? Use the word receptor in your answer.

Points	Criteria	Examples
2	COMPLETE UNDERSTANDING - Must show understanding of complementarity - I.e., mention that sour molecules don't fit into the sweet receptor OR the lemon doesn't have sweet molecules to fit into sweet receptors	It tastes sour because it fits in the sour receptor and not the sweet one. (50) A lemon tastes sour and not sweet because the taste shape doesn't match with the sweet receptor (60) Lemon taste sour, not sweet, because the shape of the lemon molecule goes into the sour section/receptor. And the sweet receptors only accept the "sweet shaped" molecules, and so lemon molecules get rejected. (12) A lemon tastes sour not sweet because the lemon molecules attaches to the sour receptor not the sweet receptor. (29)

1	PARTIAL UNDERSTANDING -Provides an answer that is correct, but is not entirely clear whether they understand the concept of taste molecules fitting into appropriate taste receptors. - Answer must specifically mention a sour receptor or sweet receptor	The sweet receptor doesn't read that taste, so the sour receptors taste it. (32) A lemon tastes sour and not sweet because of first, the acidity. Second, the sour/bitter receptors process it as sour/bitter. (49)
0	NO UNDERSTANDING - Provides an answer that does not demonstrate understanding of how specific receptors identify their specific taste - Mentions receptors in general, without specifying which receptor attaches to specific molecules	Lemons taste sour and not sweet because the receptors categorize it as sour. (31) [Didn't specify which receptors.] The receptors weed out the taste from the lemon and send signals to the brain that the lemon is sour. (9) [Didn't specify which receptors.]

Appendix K

Answer Key for Multiple-choice/Short-answer Test

Questions 1 – 8 are worth 1 pt each

1. b (if answer c, then give 0.5 pts)
2. d
3. a
4. c
5. a
6. b
7. c
8. b

9. 1 pt – Looks like an onion (with a small opening at the top)

10. 1 pt – savory or yummy taste
    0.5 pt – "It tastes like meat or cheese"
    Spelling doesn't matter (eg, unami, etc.).

11. 1 pt – umami (or savory) and salty
    0.75 pt – Two tastes (salty + something else aside from umami OR umami and something aside from salty)
    0.5 pt – One taste - salty or umami (savory), but no others
    0.25 pt – One taste other than salt or umami

12. 1 pt – Full answer: Cats cannot taste sweetness because they don't contain one of the proteins (T1R2 or one part) that is needed for the sweet receptor to work
    [Answer should demonstrate that they understand that the missing part is needed for the sweet receptor to work, or that you need two parts to taste sweetness.]

    0.5 pt – Partial answer: Because they don't have T1R2.
    [Only 0.5 pt because it doesn't demonstrate how it relates to the sweet receptor]

    Examples:
    Because their taste buds have 1 protein. You need 2 to taste sweetness. → 1 pt
    Cats cannot taste sweetness because they are missing the TIR2 protein to taste sweetness. → 0.5 pt
    They don't have T1R2 proteins so it doesn't care to them whether or not their food is sweet → 0.5 pt
    Because they don't have the T1R2 protein → 0.5 pt
    They don't have a sweet receptor → 0 pt
    Because they don't have T1R1 → 0 pt

13. The diet pill has a chemical that: (possible answers are provided below – all worth 1 pt)
   - prevents sugar from entering taste buds
   - changes the shape of the sugar molecule
   - prevents (blocks, etc.) sugar molecules from attaching to the sweet receptor
   - knocks out, disables, etc. the sweet receptor in the taste bud
   - decreases the number of sweet receptors
   - change the shape of the sweet receptor
   - blocks the signal from traveling to the brain

0.5 pt – Answers that are more general or vague—yet plausible. Or refers to sweetness taste buds instead of sweetness receptors.

0.5 pt – Answers that are correct, but also include a misconception
Ex: "I think it reduces the sweet receptors and umami and sweetness taste"

Examples of 1 pt:
It takes away the T1R2 protein.
The pill blocks the sweet receptors on your tongue so the sweet molecules will be unable to attach.
It could destroy the receptors that taste the sweetness.
It alters sweet receptors for a certain period of time.

Examples of 0.5 pt:
Reduce the protein to enable us to taste sweetness.
To have the shape to fit into our taste receptor for sweetness and ha[ve] no sweetness at all. [Technically incorrect- but right reasoning—anything that blocks sugar from fitting in.]
It blocks the sugar molecules. [Doesn't explain what the sugar molecules are blocked from.]

Examples of 0 pt:
It blocks the taste buds.
It locks off the ability to taste sweetness in the receptor so that every thing sweet taste the same.
That the opening of the taste buds will close.

Appendix L

Data Collection Protocol

Session 1: Administration of Vocabulary Section of GMRT

Hi everyone. My name is Yuna, if you don't remember my name from last week. Thank you so much for deciding to participate in my research. Last week, I came to your class and said there would be three sessions. In today's session, we'll be taking the first part of a standardized test. Just to remind you, your scores will not count toward your grades and no one will be able to identify your answers.

First, I need to get some initial information about who you are. I'm going to hand out an envelope to everyone. Please don't open it until I tell you to do so.

[Distribute envelopes with numbered index card and blank answer sheet for GMRT.]

Please look inside your envelopes. You'll see an index card with a number on it. This is the number that you will use on all the sheets that you fill out for this study. I would like you to write four things on the front of this card:

1. On the first line: Your first and last name
2. On the next line: Your gender M or F
3. On the third line: Your science teacher's name and school
4. On the fourth line: Your grade

[Provide large, visible example on the board.]

Next, inside the envelope, you will find a blank answer sheet that is part of the reading test. Please write your number in the upper-right hand corner. The reason for the number is so that when I read your answers, I won't know whose answers I'm reading. It will keep your answers confidential.

[Pass out GMRT test booklets and proceed with the test protocol for the vocabulary section.]

[Before collecting envelopes:]
Please take a moment to do the following:

1. Double check that all the information is on the index card
2. Check that you wrote the number from the envelope on the answer sheet of the test.
3. Make sure that both the card and answer sheet are in the envelope.
4. Please pass them forward.

Thank you for participating today. I will be back next week with the second part of the study.

Session 2: Administration of Reading Comprehension Section of GMRT and Prior Knowledge Questionnaire (PKQ)

At the start of class:
1. Determine if anyone was absent last week. Those students will need to create an index card.
2. Make note of anyone absent this week.

Hi everyone. Last week, you took the vocabulary portion of the standardized test. Today, you will take the second part—the reading comprehension part of the test. After you finish the test, I will give you another sheet that asks you some questions about a specific science topic. Don't worry if you can't answer all the questions. I just want to see how much you know. Again, your answers will be kept confidential and will not count toward your grades.

Now, I am going to hand out your index card, your answer sheet from last week, and an empty envelope to everyone. Please keep your index card and answer sheet face down.

[Distribute index card, answer sheet, and envelope.]
Please check your index card and make sure that you have the correct answer sheet. Place the index card in the envelope. I am now going to pass out the test booklets. Please keep them closed until we start the test.

[Distribute test booklets and proceed with the test protocol for the reading comprehension section. Remind students that they should not write in their test booklets, and that once they are finished, they should place their answer sheet in the envelope and raise their hand. Remind them that they will receive another sheet with some questions about a science topic.]

[Pass out the PKQ to each student who finishes the reading comprehension section. Remind them to write their identifying number in the upper right corner and to place the sheet in the envelope when they are finished. Tell students they won't necessarily know all the answers, but to do the best they can.]

Session 3: Experimental Passage and Tests of Learning

[At the start of class:]
1. Note anyone absent this week.

Hi Everyone. Thanks for coming today. In the past two sessions, you took a standardized test. Today, you'll read a passage about a science topic and write about what you learned. Remember that this is not graded and all your answers will be confidential.

I'm going to pass out your index card, a sheet with the reading passage, and an empty envelope. Please write your identifying number in the upper left corner of the sheet and then keep it face down. I need to provide a few important instructions before we start.

[Distribute index card, sheet with the experimental passage, and empty envelopes. The three experimental passages should be passed out in sequential order—that is, student 1 receives treatment 1, student 2 receives treatment 2, student 3 receives treatment 3, student 4 receives treatment 1, student 5 receives treatment 2, and so on.]

1. As I said, you will read an article. There are instructions at the top of each page. Please make sure to read those instructions and to follow them carefully. Once you finish reading the article, you will not be allowed to read it again, so take your time. Feel free to read it a couple times.
2. Once you finish reading, please raise your hand. I will hand you another piece of paper so that you can write what you learned. Once you finish with that paper, you can raise your hand again, and I'll give you another page with some questions.
3. Once you are finished with each page, you won't be allowed to go back, so please take your time in answering the questions.

Does anyone have any questions? OK, are you ready? Let's start.

Today, we are going to read an article about how we are able to taste sweetness. [Hold up a carton of vanilla ice cream] Does everyone see this? What is it? Vanilla ice cream--Yum! Now, imagine if you lost your ability to taste sweetness. What would that this taste like? [Point to container and pause.] As I said, the article that you are going to read talks about how we taste sweetness. Remember, read the instructions carefully, and take your time reading because once you finish, you won't be allowed to read it again. You can turn your papers over and start.

[Walk around the room and make sure that students draw a star in the upper right corner, which indicates they have read the instructions. If a student hasn't drawn the star, point them back to the instructions.]

[As students raise hands when they finish, have them place the sheet in their envelope and hand them the next learning assessment in the following order: the free recall (Part A), the short-answer performance questions (Part B), and the multiple-choice test (Part C). They should write their number on all the sheets they receive. As students finish each assessment (Part A, B, and C), they should place the sheet in the envelope before being given the next one. Collect envelopes once students complete the packets.]