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Detecting coherence breaks while reading scientific explanations

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ABSTRACT

DETECTING COHERENCE BREAKS WHILE READING SCIENTIFIC EXPLANATIONS

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Scientific passages are important because they provide information about how the world functions, and therefore, are ubiquitous in school contexts and necessary for STEM education. Because of their importance, it is crucial to identify and study factors that impede their comprehension so that educators know how to help readers understand them more deeply. Indeed, past research on the comprehension of science texts has shown that they are typically difficult to comprehend (Graesser, 1981; Millis, Graesser, & Hamberlandt, 1993). Given the difficulty of scientific passages, it would be informative to understand how readers create a *coherent representation* of the text while reading by connecting ideas within the text. One way to assess readers' coherence building is by examining whether they notice when information in the text is inconsistent. Readers often do not consciously report problems in scientific passages (explicit detection) (Glenberg, Wilkinson, & Epstein, 1982; Noordman, Vonk, & Kempff, 1992; Otero & Kintsch, 1992). Therefore, researchers have tried to examine coherence building *during* reading. They found that, at least under optimal circumstances, readers do spontaneously generate inferences while reading (Singer & Gagnon, 1999; Wiley & Myers, 2003). These findings provide indirect evidence that readers are detecting breaks in causal coherence, as bridging inferences can be generated as a means to repair breaks in coherence during reading

(Otero & Kintsch, 1992). However, no research has provided direct evidence that readers detect breaks in causal coherence while reading science texts.

The aim of the current dissertation therefore is to examine (1) whether readers spontaneously detect coherence breaks within scientific explanations as measured by reading times (implicit detection), (2) whether implicit detection depends on reading skill or task instructions, and (3) whether measures of implicit detection and conscious awareness of a problem (explicit detection) converge. Participants read short passages presenting a scientific explanation of a phenomena (e.g., how honey is formed) that included an inconsistency between the events of the causal chain. Both implicit (reading times of target statement when inconsistent vs consistent) and explicit detection (rating of how inconsistent the target statement was when inconsistent vs consistent) were examined. The results suggest that regardless of reading skill or task, participants took longer to read the target sentences in the inconsistent condition than the consistent condition. However, probing questions about awareness of the inconsistencies indicated that regardless of task or reading skill, participants were not aware of the inconsistencies. These results suggest that readers detected the break in coherence created by the conflicting words within the sentence (e.g., cooled-heated), but are not detecting the break in causal coherence between the events of the explanation. In addition, detecting a coherence break between conflicting words while reading does not lead to explicit awareness that an inconsistency had been encountered.

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DEDICATION

To Mom and Dad, for showing me what it means to be committed whole-heartedly to something,

and to Chloe, for always believing in me

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CHAPTER 1

INTRODUCTION

Suppose you are asked to read the following passage about how honey is formed:

> Bees store nectar inside a special stomach, separate from where food is stored, called the honey stomach. Enzymes in this special stomach break down the nectar into sugars and water. This broken down nectar and water is regurgitated into the honey cell of the hive. The bees begin to move their muscles. The movement of the wing muscles cools the surrounding air and the honey cell. The heated water inside of the cell evaporates.

While you were reading the passage, you may have noticed the inconsistency between the meanings of the final two sentences. The second to last sentence describes the temperature of the honey cell as decreasing, but the subsequent sentence describes the honey cell's contents as being heated. If you noticed this inconsistency while reading, you were presumably attempting to connect the different elements expressed in the text.

Connecting the ideas explicitly mentioned in a text is critical for acquiring a complete representation of the text. These connected elements form a network of information in memory that represents the reader's understanding of the text. By making these connections, the reader establishes *coherence* within the network forming in memory. Coherence refers to the extent to which the information within the network is meaningfully or logically connected together. Establishing coherence is assumed by theories and models of discourse comprehension to be a primary goal of comprehension (Gernsbacher, 1997; Kintsch, 1988; McNamara, Kintsch, Songer, & Kintsch, 1996; McNamara & Magliano, 2009; van den Broek, Risden, Fletcher, & Thurlow, 1996; Kintsch & van Dijk, 1978; Zwaan & Radvansky, 1998). A coherent understanding means that ideas from the text, together from activated ideas from long-term memory, are connected in the reader's memory in a way that makes sense to the reader.

Although the dissertation will expand on these ideas, a coherent representation is generally achieved when incoming words and ideas can be connected or "mapped" onto the existing mental representation of the current passage (termed the passage representation) when they reside in working memory. Making connections is contingent on the incoming text being related to a node (i.e., proposition or idea) in the passage representation that is also residing in working memory. There are many ways in which concepts and events can be related, and readers can use these different relationships to identify what content should be subsequently mapped onto each other (e.g., semantically, referentially, conceptually, logically, temporally, or causally). One example of a referential connection would be knowing that "this special stomach" (sentence 2) refers to the "honey stomach" mentioned in the prior sentence. Establishing coherence is a complex mechanism because the passage representation not only contains the explicit text but also inferences generated by the reader. An incoming idea might be mapped onto the passage representation by virtue of an inference. For example, consider the sentences "Suddenly, the building shook. All over town, people were jolted awake." It is plausible that a reader would infer that "an earthquake occurred" by the time the second sentence was read. This inference would allow the reader to connect the two sentences by virtue of knowledge about earthquakes (i.e., earthquakes shakes things; shaking wakes up sleeping people). Without this inference, the two sentences would seem unrelated. Either of these processes may provide a challenge for the typical reader, especially for unfamiliar material.

Although there are several types of science texts (Meyer & Rice, 1982), of particular interest to the present dissertation are causal scientific explanations like the honey example above. Explanations are an essential component of science fields because they provide an account of the how different processes occur and how a phenomenon is brought about (e.g., how the body is cooled by sweat) (Britt, Richter, & Rouet, 2014; Osborne & Patterson, 2011) and students are expected to understand them (Achieve, 2013; Council of Chief State School Officers, 2010). Research has found that scientific explanations are typically challenging for undergraduates to comprehend (Hastings, Hughes, Britt, Wallace, & Blaum, 2016; Millis, Morgan, & Graesser, 1990). Given the importance of this type of text, it is important to better understand how readers create a coherent representation of the type of text while reading.

Researchers have examined coherence building *during* the reading of science texts. Using reading time measures, research found that readers do spontaneously generate bridging inferences while reading to create a more coherent representation (Millis & Graesser, 1994; Singer & Gagnon, 1999; Singer, Harkness, & Stewart, 1997) but not under all circumstances (Noordman et al., 1992; Wiley & Myers, 2003). Bridging inferences provide a conceptual link between a sentence and a previous sentence. These studies examined inferencing as a method of determining whether readers were constructing a connected, coherent representation. They did not examine whether readers could detect an actual coherence break.

The only studies we know of that have looked at detecting coherence breaks for scientific texts used an explicit report method (Otero & Kintsch, 1992). In these studies, readers answered post reading questions in which they had to state whether they noticed whether information in the passage was inconsistent. These studies generally found that readers do not report encountering problems (Glenberg et al., 1982; Otero & Kintsch, 1992). As these authors note, this method does not mean that readers were not trying to connect information while they were reading. Thus, research is needed to understand whether readers detect breaks in causal coherence *while* reading science texts.

Researchers have used different ways to introduce changes in coherence within a text. Some researchers have used falsehoods, where one sentence in a text is incoherent with the reader's prior knowledge (Vosniadou, Pearson, & Rogers, 1988). For example, "the water began to levitate out of the glass" is in conflict with our prior knowledge that things do not levitate on their own. Other researchers have used contradictions where the *explicit* meaning of two sentences conflict with one another (Otero & Campanario, 1990; Otero & Kintsch, 1992). For instance, the statements "superconductivity is caused by heating [...] superconductivity is caused by cooling" create a contradiction because the meaning of the second statement explicitly states the opposite of the first statement. Other researchers have used the term discrepancy as a specific type of contradiction when the statements come from two different sources (Braasch, Rouet, Vibert, & Britt, 2012). These statements can vary from factual contradictions (e.g., Jeremy said over 10 people came to see the play [...] Thomas said only 5 people attended) to opposing opinions (e.g., Jeremy said the play was the worst he had seen [...] Jackie thought the play was one of the best she had attended). A final method of introducing changes in coherence is referred to as an inconsistency (O'Brien, Rizzela, Albrecht, & Halleran, 1998). An inconsistency is similar to a contradiction, but rather than the explicit meaning of two sentences conflicting, the conflict arises between some associated information or the relationship between concepts. For the nectar example above, the target sentence (The heated water inside of the cell evaporates) was either inconsistent with the prior sentence (The movement of the wing muscles *cools* the surrounding air and the honey cell) or consistent (The movement of the wing muscles *warms* the surrounding air and the honey cell). The conflict arises between the associated knowledge that the cooling of the cell would also cool the water inside. This associated information then conflicts with the subsequent sentence that the describes the water as heated. During the literature review, I will make note of the particular type of coherence disruption that was included in the study. It is important to note however that although these different variations exist, they all create a coherence break that can be detected by the reader.

The current dissertation used inconsistencies to examine whether readers detect coherence breaks spontaneously while reading science texts by using an implicit detection measure based on reading times and an explicit detection method based on answering questions after reading a set of scientific passages. *Implicit detection* refers to a situation where the reader encounters a disruption in normal processing, but does not necessarily become explicitly aware of the inconsistency. In contrast, *explicit detection* is defined as conscious awareness that an inconsistency is present within the text. I was interested in whether both measures converged on the same processing account. For implicit detection, longer reading times on the target sentence in the inconsistent condition than in the consistent condition would indicate that the reader was attempting to make a coherent representation of the passage. For explicit detection, after reading all the texts, readers rated how inconsistent the target statement is with the rest of the information in the text.

Because creating a coherent representation of scientific explanations requires both the skill in connecting text elements and requires knowledge of the text structure, it may be that only skilled readers will spontaneously detect the coherence break. It may also be that readers need to be told what to look for and how to do it. Thus, it may be that only readers instructed in creating a coherent representation of the explanation will spontaneously detect the coherence break. Thus, this dissertation will examine whether reading skill or task instructions moderate this implicit detection.

CHAPTER 2

LITERATURE REVIEW

In this section, I will provide an overview of theoretical and empirical work that motivates a set of hypotheses about detecting coherence breaks in texts. First, I will briefly present the structure of scientific explanations. Then I will present a brief overview of the current state of the field for how readers comprehend text and create coherence. Then I will present several text based factors that can influence coherence mostly to show what needs to be controlled in text passages. The section on reader factors (reading ability and task goals) will present two factors that were addressed in the experiment. Finally, I will review the literature on establishing coherence and detecting coherence breaks in science texts; in particular, what is known about when readers make inferences and detect coherence breaks. Finally, I will present an overview of the current study.

CHAPTER 3

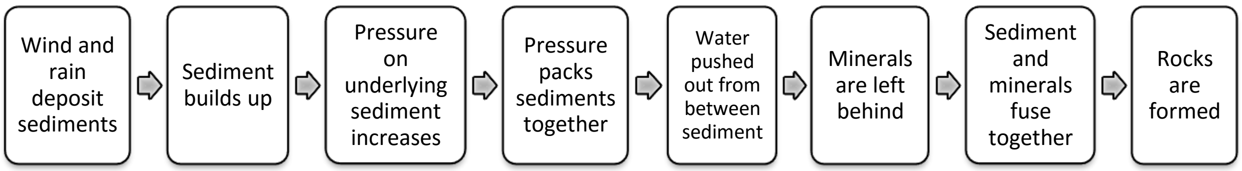
STRUCTURE OF SCIENTIFIC EXPLANATIONS

Science texts convey information about the world that has been established by scientific research. For instance, a text may describe the structure of an atom or the process of tornado formation. The exact structure of the text will vary based on the type of information that is being conveyed. As a result, different text structures have been proposed for scientific texts (Grimes, 1975; Meyer & Freedle, 1984; Meyer & Rice, 1982). Briefly, descriptive texts present the components and details of a particular object or concept (e.g., structure of a car engine). Collections present a set of objects or concepts that share a similar characteristic (e.g., types of eagles), whereas comparison texts present the similarities and differences between a set of topics (nuclear reactors vs. thorium reactors). Response texts discuss a problem and a proposed solution to address the problem (e.g., solutions for declining honeybee populations). Finally, causal texts present a series of events that share causal relationships (e.g., how sedimentary rocks form).

The causal structure is particularly important for scientific explanations. An explanation is an account of the series of mechanisms that bring about a particular phenomenon (e.g., how sedimentary rocks form). Consider the example explanation about how sedimentary rocks are formed in Figure 1.

Figure 1

Example causal explanation about the formation of sedimentary rocks.



The first event in the chain (wind and rain deposit sediments) is called the *initiating factor* (Britt et al., 2014). The series of events and states that result from this initial event are known as *explanandum* (Osborne & Peterson, 2011). These subsequent events lead to the to-be-explained outcome, termed the *explanans*.

In order to comprehend the explanation, readers must understand the underlying causal structure. The causal structure is used to relate the different events to one another and to the to-be-explained outcome. Although other types of relationships can be expressed in an explanation (e.g., temporal, enabling), most often each event within the chain causes the subsequent event. As a result, it is critical for readers to recognize this underlying structure to connect the events as they are stored in memory. If readers fail to recognize this structure, they may fail to miss breaks in coherence created by gaps and inconsistencies that can arise within a text (Wittwer & Ihme, 2014). For instance, Todaro, Millis, and Dandotkar (2010) found that readers who linked text details via semantic overlap missed coherence breaks that arose between details that shared causal relationships. However, Todaro et al. (2010) used 2-sentence narratives instead of longer expository texts. Factors contributing to detecting breaks for scientific texts are relatively unexplored and unknown. The current study will therefore examine whether readers spontaneously detect causal breaks in coherence within scientific explanations.

CHAPTER 4

AN OVERVIEW OF COMPREHENSION AND COHERENCE

While reading, incoming words activate concepts stored in long-term memory. The words and activated concepts are connected into a network to form a passage representation for the text. A passage representation contains at least three different types or levels of representation (van Dijk & Kintsch, 1983). The surface structure refers to a verbatim representation of the information from the text (e.g., exact wording, fonts). This level of representation degrades from memory quickly and is assumed to have little impact on comprehension once the other levels are constructed from it (McNamara & Magliano, 2009). However, some exceptions do occur when retaining the surface structure is important (e.g., arguments, literary texts) (Kintsch, 2004). From the surface structure, propositions are encoded which contain the concepts activated by the explicit text. This representation is known as the textbase (Kintsch, 1988). Because the textbase is restricted to the content from the text, it lacks any information that is not explicitly mentioned. Any missing information is added to the final level of representation, known as the *situation model* (van Dijk & Kintsch, 1983) or *mental model* (Johnson-Laird, 1983). The situation model contains the information from the textbase as well as inferences drawn from the reader's general knowledge (Kintsch, 1988).

As mentioned earlier, a critical feature of a passage representation is that it is *coherent*. Coherence arises when portions of the representation are meaningfully and logically connected to each other or with incoming text elements (McNamara & Magliano, 2009). It is important to note that not all texts may be coherently represented by the reader or listener. For example, a reader of an obscure poem or the listener to the ramblings of a drunk may never achieve a coherent representation. However, for most texts, it is possible for coherence to be achieved.

One way that coherence can arise is through a mapping process that connects propositions derived from the incoming text to the existing textbase (Gernsbacher, 1997; Kintsch & van Dijk, 1978). Most models of comprehension assume that the mapping occurs within a limited working memory. Because the passage representation for the text will typically exceed the limits of working memory, only a portion of the textbase is available to working memory at any given time. Also because many sentences exceed the limits of working memory, most models of comprehension assume that the mapping process is done through cycles. At each cycle, a portion of the incoming text is read (typically a clause at a time) and the reader attempts to map that input to the textbase which had remained active in working memory from previous processing cycles (Long & Chong, 2001; Myers, O'Brien, Albrecht, & Mason, 1994; Kintsch & van Dijk, 1978). For instance, the model proposed by Kintsch and van Dijk (1978) specifies rules in which the mapping is done, namely the most connected propositions remain in working memory as the rest of the passage representation dangles into long-term memory. In that model, the incoming text element is linked to the textbase via argument or lexical overlap (common concepts conveyed by nouns or adjectives, or embedded propositions) or by semantic overlap. For example, when reading the sentence "The movement of the wing muscles cools the surrounding air and the honey cell" one proposition that would be encoded would be COOLS (MOVEMENT, CELL), and one of the propositions encoded from the subsequent sentence "The heated water inside the cell evaporates" would be IS-IN (WATER, CELL) and because of the common argument CELL, these two propositions would be connected via a mapping process.

In the example above, coherence is achieved through argument overlap. However, authors and speakers do not always use the same word or expression to refer to the same entity, and they may switch topics within a text. According to Kintsch and van Dijk (1978), if there is no common argument between the incoming text and the textbase in working memory, then the reader would attempt to reinstate one by activating other parts of the textbase not currently residing working memory. This might be done by a deliberatively conscious process, or by a passive process in which the incoming words activate semantically similar concepts in long-term memory (including the textbase), a process known as resonance (Albrecht & Myers, 1995; Lea, Mulligan, & Walton, 2005). For example, an author might have continued the sentence "The movement of the wing muscles cools the surrounding air and the honey cell" with "Within the structure, water…". The word "structure" may activate features associated with "cell", which allows the reader to make a connection. Presumably, semantically semantic similarity between concepts enables connections to be made, preserving coherence.

A bit more recently, Kintsch (1988) proposed the construction-integration (CI) framework for comprehension that address how coherence might be achieved solely via passive mapping mechanisms. The framework assumes that in an initial construction phrase, incoming words activate semantic associations in a "dumb" and passive fashion. It is "dumb" because the pattern of activation is not guided or restricted based on context. In the integration phrase, a settling process occurs across the pattern of activation, in which inappropriate word meanings become less activated, leaving more appropriate meanings to remain activated. The integration process is dominated by a settling procedure found in parallel distributed models. One might think of this as a more contemporary way of establishing connections based on the explicit text and activated knowledge than earlier models (i.e., Kintsch & van Dijk, 1978). However, the model does not specify how coherence is achieved beyond the settling process or if the settling process is not successful in creating a connected representation.

The models proposed by Kintsch emphasize that activations of word meanings and explicit text propositions are mapped, leading to a coherent representation. Whether the mapping is done at the textbase or situation model level can be unclear. One way that mapping is achieved at the situation model is through knowledge-based inferences that come from the reader's understanding of the topics conveyed by the text (Graesser, Singer, & Trabasso, 1994). For instance, readers can generate a bridging inference to connect information from the current sentence back to a prior sentence (Kintsch, 1988; Singer & Gagnon, 1999; van den Broek, Lorch, Linderholm, & Gustafson, 2001; Wiley & Myers, 2003). Consider sentences in 1a below:

1a. Dylan reached for the baking soda. The oil fire on the stove went out.
1b. *Dylan poured the baking soda onto the oil fire.* (Inference)

There is no explicit connection made between Dylan reaching for the baking soda and the oil fire subsequently going out. However, there are probably common semantic associations to the words in the sentences that can be integrated along the lines of the CI framework. For example, "baking", "fire", and "stove" seem to be semantically related, and therefore, could help establish coherence. But it is unclear whether the representation achieved through the CI model would include the inferred proposition in sentence 1b ("Dylan poured the baking soda onto the oil fire"). Instead, the verb "pour" might be activated along with the other associates, but it may not express the full inference. So, it is not clear whether the CI model can account for knowledge-based inferences like the bridging inference described here. Instead, the inference could be achieved through a controlled process in which the reader searches episodic memory and finds a node that "baking soda puts out fires", or by a prolonged reasoning process.

In regards to the situation model, readers create connections based on causality and temporality (Zwaan & Radvansky, 1998). For example, Zwaan, Magliano, and Graesser (1995) had participants read narrative texts that naturally varied in causal continuity, temporal continuity, and spatial continuity. Sentence reading time data revealed that participants took longer to read points in the text that contained causal or temporal discontinuities. This sensitivity to causal or temporal continuity changes suggests that readers represent these links to construct a coherent passage representation. When one sentence does not continue in regards to causality and temporality from the previous sentence, the reader slows down to update the situation model of these dimensions. In essence, the evidence shows that readers monitor causality and temporality.

Coherence can be also achieved via higher-order knowledge structures that signal particular relations among text elements. For example, coherence relations, such as cause-effect and problem-solution, are relationships that can be represented within the passage representation, but go beyond simple argument or semantic overlap (Sanders & Noordman, 2000). In addition, these types of rhetorical structures can account for how larger text units, such as paragraphs, are conceptually connected. For example, one paragraph might describe a problem, and the next, a possible solution (Meyer, Brandt, & Bluth, 1980; Meyer & Freedle, 1984).

The above discussion summarizes mechanisms thought to routinely preserve coherence during comprehension. However, coherence breaks arise from instances where the incoming text element either contradicts earlier encoded text propositions, fails to map onto the information within the passage representation (O'Brien, 1995), or where the level of coherence does not reach the level of coherence expected by the reader (Otero, 2002; van den Broek et al., 2001). A wealth of research using narrative passages has shown that readers routinely and spontaneously detect coherence breaks while reading (Albrecht & Myers, 1995; Albrecht & O'Brien, 1993; Cook, Halleran, & O'Brien, 1998; Myers, et al., 1994; O'Brien & Albrecht, 1992; O'Brien & Myers, 1985; O'Brien et al., 1998). As mentioned earlier, there is less research on detecting coherence breaks for scientific passages.

In sum, coherence can be achieved by mapping concepts which have been either explicitly mentioned in the text or implicitly activated by the explicit text. The concepts can range from low-level word meanings to higher-order structures that help the reader to connect text units. Let us consider how the mechanisms summarized above might account for the comprehension of the last two sentences of the Bee example which pose a coherence break. The sentences are:

> "The movement of the wing muscles cools the surrounding air and the honey cell. The heated water inside of the cell evaporates."

It first should be noted that argument overlap is possible between the two sentences by virtue of the concept CELL. Therefore, at least on the textbase level, a coherence break between the two sentences is not apparent. Instead, the coherence break is based on the situation model. It occurs if the reader inferred that the muscle movements cools the entire honey cell, including its contents. A coherence break occurs because the second sentence contracts the idea that all of the water in the cell should be cool. Note that this requires a logical inference of transference; something like "if x acts on a structure/container then x acts on the contents of the structure/container as well." This inference may not be generated by the passive mechanisms of the CI model, although it is conceivable that the opposite words of "cool" and "heat" may affect the integration process. But the inference would not be triggered by the lack of argument overlap since argument overlap could be achieved. It should only occur to the extent that the reader is building a causal model of the mechanism described by the text. Could a reader repair the break? At least in this instance, it could be repaired if one represents the "heated water" as being separate and immune to the cooling effect of the wing muscles. One should also add that the determiner "the" introducing "heated water" denotes an entity which is presumably known to the reader (Haviland & Clark, 1974). Signaling the contradictory piece of information in this manner probably will impede a reader from noticing the break.

CHAPTER 5

INFLUENCES ON DETECTION OF COHERENCE BREAKS

A reader's ability to explicitly or implicitly detect a coherence break may depend on several factors. These moderating factors broadly include features of the text and characteristics of the reader. The following sections will provide brief overviews of the factors falling into each of these categories. When possible, each discussion will be limited to descriptions and examples from relevant research demonstrating the effects of these factors. First will be a discussion of the text features. These are important for detecting coherence breaks, and are controlled for in the current materials. After that, reader characteristics (reading ability and task goals) will be covered that will be examined in this dissertation.

Text Features

One aspect of the text that has been shown to impact the detection of coherence breaks is the distance between the inconsistent concepts (Baker, 1985a; Myers & O'Brien, 1998). Distance refers to the number of intervening sentences between the to-be-integrated statements. The relative proximity of these statements influences how readers check for coherence while reading (Myers & O'Brien, 1998). As was discussed earlier, most models of comprehension assume that the concepts from the prior few sentences remain in working memory as the incoming text is read (Kintsch, 1988; O'Brien et al., 1998). It was also mentioned that coherence between these proximally located concepts is obtained when the reader maps the current text input onto the passage representation which includes these already active concepts (Myers & O'Brien, 1998; O'Brien, 1995). In contrast, concepts that appeared several sentences before the current input are typically no longer held in working memory when incoming text is read (Albrecht & O'Brien, 1993; Myers & O'Brien, 1998). As a result, these concepts must first be reactivated from long-term memory by using the current input as a retrieval cue (Albrecht & Myers, 1995; Lea et al., 2005; Kintsch, 1988). Coherence between these distal concepts is therefore achieved when the backgrounded information is reactivated into working memory and then mapped onto the current text. Research with narratives has demonstrated that readers can implicitly detect both near and distant inconsistencies (Albrecht & Myers, 1995; Albrecht & O'Brien, 1993; O'Brien & Albrecht, 1992; O'Brien et al., 1998). In the current study, to avoid the possibility that readers might fail to reactivate backgrounded information or detect inconsistencies because of distance, the coherence breaks occurred between two adjacent sentences.

Related to distance is cue strength, which refers to the ability for the current text input to retrieve any backgrounded information from memory. In order to access backgrounded information, the current text input must possess a sufficient level of semantic relatedness, known as featural overlap (Myers & O'Brien, 1998). If the current text input does not possess adequate featural overlap with the antecedent (related prior) information then that information will not be retrieved (Albrecht & Myers, 1995; Lea et al., 2005). For example, Albrecht and Myers (1995) found that readers failed to implicitly detect an inconsistency between a protagonist's goals and later actions. This failure arose because the information surrounding the action failed to reinstate the earlier goal information. However, when the sentence before the action statement was manipulated to act as a stronger cue, the earlier goal information was retrieved and the inconsistency was detected. For the current materials, cue strength should not influence the availability of the sentences that create the coherence beak, as they are adjacent to each another and should still be available in working memory. However, stronger cues were used to help the reader access a prior knowledge sentence that would help them understand the elements that connect the manipulated event sentence and the target sentence. Even when an adequate cue is present, the presence of distractor information could impact whether readers detect coherence breaks. Distractors are irrelevant concepts that are also retrieved from the passage representation alongside relevant prior information. Research has shown that the current text input may activate multiple potential antecedents (Cook et al., 1998; Corbett & Chang, 1982; Kendeou, Smith, & O'Brien, 2013; O'Brien, Plewes, & Albrecht, 1990) and outdated information (O'Brien et al., 1998). This irrelevant information can limit the amount of activation the relevant antecedent information receives (Myers & O'Brien, 1998). If the distractor information is strong enough, it could possibly prevent the retrieval of the earlier information and subsequent evaluations of coherence. Therefore, in the current materials no extraneous information was included between the events of the explanation. The only extraneous (non-event) information was the introductory sentences and ending sentences at the beginning and end of each text. It was thought that the target sentences would not reactivate this earlier, extraneous information.

Reader Characteristics

Reading Skill

Reading skill has been associated with the type of passage representation created for the text. Todaro et al. (2010) found that less-skilled readers are more sensitive to changes in semantic coherence, whereas more-skilled readers are sensitive to changes in causal coherence. In the study, participants read sentence pairs that varied in their level of causal relatedness and semantic relatedness. After each sentence pair, the participants were asked whether the pairs were coherent. A set of example items can be seen below. Semantic relatedness referred to the similarity of the concepts contained within the two sentences (as in sick-doctor for 2a and nurse-doctor for 2c). In contrast, causal relatedness concerned whether the second sentence could be readily considered a consequence of the first sentence (for example calling a doctor when baby is sick, 2a, or husband collapses, 2b).

2a. High causal-high semantic: Susan recognized her baby was sick. She called her family doctor at once.
2b. High causal-low semantic: Susan's husband collapsed on the floor. She called her family doctor at once.
2c. Low causal- high semantic: Susan recently became a nurse. She called her family doctor at once.
2d. Low causal-low semantic: Susan's husband was working in the den. She called her family doctor at once.

Todaro et al. found less-skilled readers' judgments of coherence were influenced more by the semantic relatedness of the two statements than were more-skilled readers. In contrast, more-skilled readers' judgments were more influenced by the causal relatedness of the two statements than were less-skilled readers. These results suggest that less-skilled readers attempt to establish coherence at a shallower semantic level, whereas more-skilled readers attempt to establish coherence at a deeper, causal level while building a passage representation. These results have been replicated more recently using scientific texts (Wittwer & Ihme, 2014).

Reading skill is not only related to the type of passage representation that is constructed, but also to the explicit detection of coherence breaks within a text. Research has found that more-skilled readers are more likely to detect coherence breaks in science texts (Clark, Forlizzi, Ward, & Brubaker, 1988; Garner, 1980; Hacker, 1997) and narrative texts (Clark et al., 1988) than less-skilled readers. This difference is thought to arise because more-skilled readers place more importance on regularly monitoring their understanding while reading (Clark et al., 1998). By regularly evaluating their understanding, breaks in coherence become more salient, and these readers are therefore more likely to detect that a problem has arisen during reading.

Representing Goals and Strategies

The reader's purpose for reading text is expected to impact the construction of the passage representation (Rouet & Britt, 2011; van den Broek, Risden, Husebye-Hartmann, 1995). A purpose for reading can primarily arise from the reader's own goals, such as to read a passage for entertainment (van den Broek et al., 1995), or can be based primarily on some external task or set of instructions, such as to read for a school assignment (Griffin, Wiley, Britt & Salas, 2012; Wiley & Voss, 1999; Wiley et al., 2009). Regardless of whether the goal originated from the reader or from an external source, the reader will create a set of goals that they attempt to accomplish while reading.

The creation of goals for reading is described in the Multiple-Document Task-based Relevance Assessment and Content Extraction (MD-TRACE) framework proposed by Rouet and Britt (2011). Although this model is for multiple documents, the key construct of a task model can apply to single document comprehension. Specifically, this framework proposes that readers construct a mental representation for their goals for reading, known as a *task model*. The task model consists of three different components. The first component is the goal or set of goals to be accomplished during reading. For example, the reader's goal may be to understand how digestion works. The goal may prompt the reader to reach other goals or to answer other questions that may arise during comprehension, such as to explain how the intestines function. These latter goals may be referred to as subgoals. The second component is any strategies or operations the reader can use to achieve the goal and subgoals, if there are any. In the digestion example, readers may look for discourse pointers (headers, key words, connectives) in the text that indicate what parts of the digestive system structure link together. The last component of the task model is the criteria set by the reader for completing the goal. The criteria for learning the digestive system can range from simply completing a single read-through of the text to gaining an understanding of how the different body parts involved interact.

The task model affects the passage representation by directing the reader's focus to goal-relevant content and the possible relations among the concepts that arise from the text and the context (Rouet & Britt, 2011). Therefore, as the reader's goals vary, so should the resulting passage representation. Consistent with this prediction, research has shown that different types of reading tasks influences the information encoded in the passage representation, as evidenced by both memory (McCrudden, Magliano, & Schraw, 2010) and comprehension measures (Blaum et al., 2015; Gil, Bråten, Vidal-Abarca, & Strømsø, 2010a, 2010b; Wiley & Voss, 1996, 1999; Voss & Wiley, 1997). For instance, Wiley and Voss (1999) presented participants with different instructions, such as reading in order to write an argument, a summary, or a narrative. They found that the argument condition included more transformed sentences and causal connections within their essays, and performed marginally better on an inference test than the groups asked to read to write a summary or narrative. These results suggest that the passage representation created by the participants was contingent upon the type of reading task they were given.

The task model is expected to influence the passage representation a reader creates for the text (Rouet & Britt, 2011) based on the activation of schema knowledge of the target domain, such as the structure of an explanation. In part, the task model influences comprehension by directing the reader to goal-related content within the text (Anderson & Pichert, 1978; McCrudden et al., 2010; Pichert & Anderson, 1977). Considering again the digestion example from above, information about the connection between the esophagus and the stomach would be considered highly relevant to the reader's goals and should be processed deeply during reading. In contrast, information about the connection between the esophagus and the lungs would be of little relevance to understanding the digestive system, and should therefore be processed less deeply during reading. It is expected that college students will have the basic schema knowledge to create goals for these simple explanations (Meyer & Freedle, 1984; Meyer & Ray, 2011).

In addition to using schema knowledge to create goals of the task model, readers also need to have the strategies to achieve those goals. These strategies will influence the types of coherence the reader expects to be expressed between concepts in the text (van den Broek et al., 1996; van den Broek et al., 1995). Several different types of coherence can be checked during reading, including referential relationships (e.g., pronouns), causal relationships, spatial relationships, temporal relationships, or logical relationships (Lea et al., 2005; van den Broek, Virtue, Everson, Tzeng, & Sung, 2002; Zwaan et al., 1995). The particular type of coherence that readers monitor for should depend on the goals they have for reading (van den Broek et al., 1995). For example, if the goal is to understand the digestion process, readers may expect information to be temporally related (e.g., food from the mouth enters the esophagus) and causally related (e.g., stomach acids break down the food). In contrast, if the goal is to only understand the structure of the digestive tract, readers may instead evaluate the information for spatial coherence (e.g., the esophagus is located above the stomach).

In regards to comprehending scientific texts, knowledge about the structure of an explanation may also affect the task model. That is, the knowledge about scientific explanations probably would affect what information the reader would look for while reading. For example, while reading about digestion problems, the reader may attempt to reason how each event contributes to why digestion problems arise. However, as discussed earlier, readers do not appear to possess much knowledge about the structure of explanations, or how to process them (Ursin, Steffens, Britt, & Millis, 2015). Without this additional knowledge, readers may create an impoverished task model that lacks critical information for completing the task, such as checking for causal coherence (Yeagle, Steffens, Britt & Millis, 2015).

One way to avoid an impoverished task model is to provide task instructions that contain additional information and strategies about how to complete the task (Kopp, 2013). Instead of expecting that readers possess the requisite knowledge to elaborate upon their task models, the necessary information is integrated with the task. In the case of explanations, such instructions could be used to provide readers with knowledge about the causally related events and states, and strategies to use while reading about them.

The current dissertation will therefore examine whether readers detect inconsistency-induced coherence breaks when given a general task to "understand" the explanation or if they need information about the structure of an explanation and hints to strategies for achieving that structure.

CHAPTER 6

CREATING COHERENCE AND DETECTING COHERENCE BREAKS IN SCIENCE TEXTS

As was noted before, a wealth of research using narratives has found that readers routinely detect coherence breaks while reading (Albrecht & Myers, 1995; Albrecht & O'Brien, 1993; Cook et al., 1998; Myers, et al., 1994; O'Brien & Albrecht, 1992; O'Brien & Myers, 1985; O'Brien et al., 1998). Yet no research has directly examined whether coherence breaks are similarly detected while reading scientific texts. However, research on bridging inferences (Noordman et al., 1992; Singer & Gagnon, 1999; Wiley & Myers, 2003) and judgments of text coherence (Wittwer & Ihme, 2014) provide some indirect evidence of whether readers spontaneously detect coherence breaks while reading science texts. This evidence is indirect because the focus of the research was to capture causal inference generation rather than coherence break detection. Still, based on the coherence mechanisms described earlier, the processes that were measured in these studies are related to the process of coherence break detection. This section will begin by discussing these areas of research and how they connect to the detection of coherence breaks. Afterwards, there will be a discussion of the relationship between implicit detection and explicit detection of coherence breaks, followed by a short discussion of methods for measuring coherence.

Responses to Encountering Coherence Breaks

Readers generate bridging inferences in order to connect text elements within the passage representation. When a gap or conflict arises from the information in the text (Otero & Kintsch, 1992), they can be spontaneously repaired by the bridging inference. This inference is therefore evidence that the reader has detected the break in coherence and has attempted to add additional information to reestablish coherence. If readers do not appear to generate bridging inferences, it could indicate that readers may not be detecting breaks in coherence while reading.

Initial research by Noordman et al. (1992) suggested that readers do not spontaneously generate bridging inferences while reading science texts. Participants read short passages that did (explicit condition) or did not (implicit condition) mention a critical detail (3a). This detail matched an inference that could be drawn from an adjacent target sentence (3b). Therefore, the explicit condition provided the inference ahead of the target sentence, whereas the in the implicit condition the detail would need to be inferred from the target sentence.

3a. Propellants must not combine with the product in the spray can. (Explicit/inference)
3b. Chlorine compounds make good propellants, because they react with almost no other substances. (Target sentence)

Noordman et al. reasoned that when 3a was explicitly mentioned, those details would still be active in working memory when the target sentence was read. The inference drawn from the target sentence would match this active information, therefore facilitating processing and reducing reading time. In contrast, when 3a was not mentioned, readers would need to generate the inference for the first time while reading the target sentence, which would take additional processing time. Contrary to these predictions however, target sentence reading times did not vary based on the presence of the earlier sentence (3a). Based on this finding, Noordman et al. concluded that readers do not spontaneously generate bridging inferences while reading scientific texts. However, it becomes less clear whether or not readers were detecting the coherence break. Because there was no evidence of a bridging inference, it could suggest that the reader did not detect the causal break in coherence. Conversely, it may be that readers detected the break in causal coherence, but performed some behavior other than inferencing in response to the break (Otero & Campanario, 1990; Otero & Kintsch, 1992).

In contrast to the Noordman et al. (1992) findings, other research found that readers do spontaneously generate causal bridging inferences while reading scientific texts (Millis & Graesser, 1994; Singer & Gagnon, 1999; Singer et al., 1997; Wiley & Myers, 2003). For instance, Singer and Gagnon (1999) had students read short scientific passages that they had developed and that had been used in the Noordman et al. (1992) study. In the passages, a statement (4a) either did or did not contradict a causal bridging inference (4c) that would need to be drawn by the adjacent target sentence (4b).

4a. Lubricants should be good coolants.
4b. Liquid hydrocarbons are the most commonly used lubricants because they effectively **(remove/add)** heat. (Target sentence)
4c. *Lubricants should* ***(remove/add)*** *heat.* (Inference)

If readers generated the causal bridging inference, the contradiction between 4a and the inference would cause a disruption in reading that would result in longer target sentence reading times than when the sentences were consistent. Consistent with their expectations, longer target sentence reading times were found for the inconsistent passages than the consistent passages. Contrary to the Noordman et al. (1992) findings then, readers appeared to be detecting the break in causal coherence that prompted the causal inference to be drawn.

These later findings have been corroborated by the results of Wiley and Myers (2003). They employed a similar paradigm to Singer and Gagnon, but removed the connective "because" and separated the second premise statement from the target sentence. Their science passages therefore contained the critical details presented as embedded syllogisms (see example below).

5a. Metabolic rate increases with energy needs. (Premise 1)
5b. Seals usually have to produce a lot of energy just to keep warm, (Premise 2)
5c. *Seals have high metabolic rates.* (Inference)
5d. Seals have **(high/low)** metabolic rates. (Conclusion)

The causal coherence break between the two premise statements (see 5a and 5b) would cause the reader to spontaneously generate a causal bridging inference (5c). This inference did or did not contradict the conclusion statement (5d). Longer reading times were found when the inference and conclusion were contradictory than consistent, suggesting that readers were spontaneously generating the causal bridging inference. Therefore, these findings too suggest that readers were detecting the causal break in coherence while reading.

Besides research on causal bridging inferences, other work has found that readers are sensitive to variations in coherence in science texts. Wittwer and Ihme (2014) had participants read explanations about different physics phenomenon. The explanations were manipulated to be either have high causal specificity (e.g., "this [process] results in an increase") or low causal specificity (e.g., "this [process] has an influence). Additionally, the explanations were high in semantic overlap (i.e., explicit noun overlap) or low in semantic overlap (i.e., pronouns). Wittwer and Ihme found that more-skilled readers' judgments were influenced by causal specificity, whereas less-skilled readers' judgments were influenced by semantic overlap. These variations in judgments suggest that readers are noticing the changes in coherence that arose in the text. But because the findings were based on explicit judgments, it is still an open question whether similar findings would occur if the readers were not asked about them. Also perceptions or judgments of coherence may be ambiguous because they may be measuring the reader's perception of the coherence of their mental representation of the text (as intended by the authors) or simply their reactions to the properties of the text, something akin to cohesion. Coherence refers to the mental representation of the text and cohesion refers to aspects of the text themselves.

In sum, these areas of research provide somewhat strong but indirect evidence that readers detect coherence breaks within scientific texts. But because these areas of research were not examining coherence break detection *per se* but rather inferential processes, the question of whether readers spontaneously detect coherence breaks while reading scientific texts remains unanswered. The current study therefore aimed to provide some initial evidence to answer this question.

CHAPTER 7

IMPLICIT DETECTION AND EXPLICIT DETECTION OF COHERENCE BREAKS

When a coherence break arises from the text, readers may become consciously aware that a problem arose during reading. This awareness of a problem or inconsistency is defined as explicit awareness. The ability to explicitly detect these inconsistencies is indicative of the reader's ability to monitor coherence between ideas in the text (Baker, 1985a). If readers regularly detect inconsistencies, they are likely to be evaluating the coherence of other information within the passage as well. However, research has shown that readers have difficulty explicitly detecting problems within texts, with detection rates ranging from 40% to 60% (Baker & Zimlin, 1989; Glenberg et al., 1982; Noordman et al., 1992; Otero & Kintsch, 1992).

It is assumed that implicit detection is a necessary precursor for explicit detection. Therefore, readers that fail to implicitly detect a coherence break should also fail to explicitly detect the break (Clark et al., 1988). After implicitly detecting a coherence break however, readers may or may not become consciously aware that a break occurred (Otero & Campanario, 1990; Otero & Kintsch, 1992). Readers will not become aware of the coherence break if they perform some reparative action that reestablishes coherence within their passage representation.

For instance, Otero and Kintsch (1992) placed two contradictory statements within short scientific passages (see 6a and 6b).

6a. Until now [superconductivity] has only been obtained by cooling certain materials to low temperatures near absolute zero.
6b. Until now superconductivity has been achieved by considerably increasing the temperature of certain materials.
6c. *In the past, superconductivity was obtained by cooling materials, but it is now obtained by heating materials.*

After reading participants were asked to recall the passages. Analysis of the recalls revealed that a portion of participants had fixed the contradiction by generating a bridging inference (6c). However, these same participants did not report noticing any contradictions when asked after reading. The presence of the inference suggests that readers implicitly detected the coherence break during reading, but the failure to report any issues suggests that the inference prevented explicit detection of the contradiction. Other readers may manipulate the meaning of a text element in the passage representation in order to repair a coherence break (Hakala & O'Brien, 1995), or detect the problem but deem it unimportant or irrelevant (Baker, 1979; Otero & Campanario, 1990). However, by repairing the coherence break, these readers "fix" the problem and continue on without becoming fully aware that a problem had occurred.

Given the number of behaviors that readers can perform in response to a coherence break, it would be informative to examine the relationship between implicit detection and explicit detection. However, research has often focused on implicit detection alone (Albrecht & O'Brien, 1993; Myers et al., 1994; O'Brien et al., 1998) or explicit detection alone (Baker & Zimlin, 1989; Glenberg et al., 1982; Noordman et al., 1992; Otero & Kintsch, 1992). Therefore, the current study included measures of implicit detection and explicit detection in order to examine how the two are linked.

Measuring Implicit Detection and Explicit Detection

There are many different methods that have been used to measure the influences of coherence and the detection of coherence breaks. For example, research has used think-alouds, where participants are prompted to report their thoughts after every sentence or after target sentences (Coté, Goldman, & Saul, 1998; Millis et al., 1990; van den Broek et al., 2001). Other researchers have varied the coherence of the information within a passage and asked participants to rate the text's understandability (Todaro et al., 2010; Wittwer & Ihme, 2014). Many studies have also used post-reading comprehension questions that assess the reader's passage representation for the text (Coté et al., 1998; Gil et al., 2010a, 2010b; McNamara, 2001; McNamara & Kintsch, 1996; McNamara et al., 1996; van den Broek et al., 2001; Wiley & Voss, 1996; 1999). Often, these questions will target areas of the passage representation where the reader would need to establish coherence while reading.

Of the available methodologies, the current study employed reading times as one measure of coherence break detection. Variations in coherence within a passage have been shown to influence reading times, with lower levels of coherence leading to longer reading times (Albrecht & O'Brien, 1993; Long & Chong, 2001; Myers et al. 1994; O'Brien et al. 1998; Zwaan et al., 1995). Reading times can therefore capture moment-to-moment construction of the reader's passage representation, including the spontaneous detection of coherence breaks. Although think-alouds could capture similar online processes, readers may require some minimum level of explicit detection in order to report encountering a coherence break. As was just discussed, readers may implicitly detect coherence breaks but not become aware that a break has been encountered. Therefore, reading times may be a more sensitive measure to the implicit detection of coherence breaks than think-alouds.

Besides reading times, the current study also used post-reading conflict detection questions. These questions asked participants to report any difficulties that they had encountered while reading (Baker, 1979; Barton & Sanford, 1993; Garcia-Arista, Campanario, & Otero, 1996; Glenberg et al., 1982; Markman, 1979; Noordman et al., 1992; Otero & Campanario, 1990; Otero & Kintsch, 1992). If readers have explicitly detected the coherence break, they should be able to accurately recognize what information led to the processing problem. These questions therefore provide a direct measure of the explicit detection of coherence breaks within a text.

CHAPTER 8

OVERVIEW OF THE CURRENT STUDY

The current study examined the conditions under which readers detect coherence breaks in texts describing scientific explanations. As mentioned earlier, one paradigm that has been used frequently to examine the detection of coherence breaks is the *inconsistency paradigm* (Albrecht & O'Brien, 1993; Myers et al., 1994; O'Brien et al., 1998). Within this paradigm, participants read passages where a manipulated statement is consistent or inconsistent with a target statement later in the text. An example text with the inconsistency manipulation can be found in Table 1. Consider the inconsistent version, where the honey cell is cooled. An earlier prior knowledge sentence (see sentence in italics) noted that the cell contained water and broken down nectar. Therefore, the decrease in temperature that happens to the honey cell should also be attributed to the water inside. This conflicts with the target sentence, which describes the water as being heated. The conflict will become apparent if the reader attempts to connect the two inconsistent events together. This conflict should create a coherence break and result in longer reading times on the target sentence than when the passage contains the consistent sentence. Answers to post-reading detection questions provide evidence of whether or not readers explicitly detect or fail to detect the coherence break created by the inconsistency.

Table 1

Example text with consistency manipulations[1]

Part of text:	Title:	How Bees Make Honey
Introduction/ start of chain (Prior knowledge sentence in italicized)		Bees are like humans in that they make their own food, honey. The process of honey production starts by worker bees seeking out flowers. The bees find flowers and begin to drink their liquid nectar. The nectar is stored in a special stomach, separate from where food is stored, called the honey stomach. Enzymes in this special stomach break down the nectar into sugars and water. *This broken down nectar and water is regurgitated into the honey cell of the hive.* The bees begin to move their muscles.
Manipulated event sentence: Consistent version		The movement of the wing muscles **warms** the surrounding air and the *honey cell*.
Inconsistent version		The movement of the wing muscles **cools** the surrounding air and the *honey cell*.
Target sentence		The **heated** *water* inside of the cell evaporates.
End of chain		The sugars inside the cell thicken, forming honey.

In the Experiment, participants read twelve consistent and inconsistent explanations under one of three task instructions. In the read-to-understand task, participants were simply told to understand each scientific explanation that they read. These instructions were created in order to give participants a general goal for reading each explanation. This condition will therefore examine coherence processes that are spontaneously used by the reader. In the Structure-only task, the instructions described the structure of an explanation and how the events should be causally related to one another. This instruction was constructed to provide students with

[1] The bold terms are the manipulated terms that are either consistent or inconsistent. The italics sentence establishes the knowledge that will later be needed to detect the coherence break.

knowledge about what an explanation is and to encourage students to construct an integrated representation for the text. In the Structure-and-Strategy task, the instructions combined the description of explanation structure with a prompt to self-explain in order to make sure everything made sense together. This instruction added to the prior instruction information about how the events are connected. In addition, reading skill differences were examined using ACT scores.

The current dissertation tested three research questions:

Research Question 1

The first research question was whether readers spontaneously detect coherence breaks within scientific explanations as measured by reading times (implicit detection). The hypothesis tested for this research question was the *Mental Model Construction Hypothesis* which assumes readers attempt to construct a coherent passage representation while reading, and will notice when breaks in coherence occur (Albrecht & O'Brien, 1993; McNamara & Kintsch, 1995; Myers et al., 1994; O'Brien et al., 1998). According to this hypothesis, readers should attempt to construct a coherent representation of the events leading to the outcome of an explanation. As argued above, attempting to make connections across sentences would make the inconsistency more apparent to the reader. Consequently, for implicit detection, a predicted main effect of Text Consistency will occur, with longer target reading times for the inconsistent passages than the consistent passages. Similarly, for explicit detection a main effect of Text Consistency will occur, with more inconsistencies being reported for the inconsistent condition than the consistent condition.

Research Question 2

The second research question addressed in this dissertation was whether either reading skill or task instructions influence implicit detection. Two separate hypotheses were tested for this research question. The *Reading Skill Coherence Sensitivity Hypothesis* assumes that more-skilled readers are sensitive to changes in the causal relationships between text elements, whereas less-skilled readers are sensitive to changes in semantic relationships (Todaro et al., 2010, Wittwer & Ihme, 2014). Given that explanations follow a causal structure (Meyer & Freedle, 1984), more-skilled readers will attempt to detect causal connections between the events while reading and as a result detect breaks in coherence when they arise between the events. Less-skilled readers however will be less likely to establish causal relationships and will therefore be more likely fail to notice coherence breaks. Based on this hypothesis, an interaction between Text Consistency and Reading Skill was expected to emerge. More-skilled readers should show a greater difference in reading times between inconsistent passages and consistent passages than less-skilled readers.

The *Task Model Hypothesis* assumes that readers have task goals and plan to reach these goals, and these guide how readers create a representation of text. According to this hypothesis, readers will spontaneously attempt to connect the events of an explanation together when they possess knowledge about the structure of an explanation because this knowledge will provide the appropriate goals for this task (Meyer & Freedle, 1984; Meyer & Ray, 2011). It was assumed that the *structural knowledge instructions* would provide knowledge regarding the structure for explanations. Additionally, knowing to self-explain and check that everything makes sense together will ensure that readers have the goal to connect the events to one another (Chi, Bassok, Lewis, Reimann, & Glasser, 1989; McNamara, 2004; Wylie & Chi, 2014). This knowledge will provide the reader with appropriate plans which were operationalized as *strategy knowledge instruction*. These instructions should help readers notice breaks in coherence to the extent that either structural knowledge or structure and strategy knowledge are not available or activated when reading. Based on this hypothesis, an interaction is expected between Task and Text Consistency. Readers given the read-to-understand task will have similar target sentence reading times for the inconsistent and consistent passages. In contrast, participants given the structure-only task or the structure-and-strategy task will have longer target reading times for the inconsistent passages than for the consistent passages. Because the combination of structure knowledge and strategies should make the coherence breaks especially salient while reading, participants that are given both instruction sets should show a larger difference in reading times between the inconsistent and consistent passages than participants who are only given the structural knowledge instructions.

Research Question 3

The third research question was whether implicit and explicit detection measures converge. According to the *Mental Model Construction Hypothesis* readers should attempt to construct a coherent representation of the events leading to the outcome of an explanation. This should lead to a main effect *of Text Consistency* for both implicit (longer reading times) and explicit (rated inconsistency) for the inconsistent condition than the consistent condition. Additionally, the difference between the inconsistent and consistent versions on reading time should correlate with the measure of explicit detection.

CHAPTER 9

PILOT STUDY

A pilot study was conducted to ensure that the texts were sensitive enough to capture the reading time boggle, and to test the strength of the task manipulation. The aim of the pilot study was not to test the hypotheses. Participants were given a task that either a) asked readers to understand each explanation or that b) provided structure and strategy information prior to reading texts that were consistent or inconsistent and. Sentences were presented one sentence at a time on the computer, while reading times were recorded.

Methods

Participants

Ninety-three introductory psychology students (mean age = 21.45, *SD* = 14.00, 53% female) from Northern Illinois University participated for course credit. The demographics were 45% white, 31% African American, 8% Hispanic, 4% Asian American, 1% American Indian or Alaska Native, and 11% mixed or self-classified other. Five participants could not complete the study due to computer failures, so their data was not used. The Institutional Review Board at the university approved all procedures.

Materials

Texts

Twelve texts described explanations about different scientific phenomena (e.g., how sweat cools the body, how a poison ivy rash forms). The topics selected were all natural processes, and did not include any man-made processes. Due to natural variations in the length of each process, the explanations varied from 7 to 11 events. Each text had the four sections: Introduction and start of chain, manipulated event sentence, target sentence and end of chain. The exact location of the inconsistency within the explanation varied, but the conflict never included the initiating event or outcome event. The length of the texts ranged from 9 to 16 sentences, with an average length of 12.16 (*SD* = 1.95) sentences. The texts had an average grade level of 7.2 as determined by the Flesch-Kincaid readability formula (Kincaid, Fishburne Jr, Rogers, & Chissom, 1975).

A List variable (List A vs. List B) was created to counterbalance the consistency of the texts. Topics were paired using Latent Semantic Analysis (LSA). LSA generates a coefficient that represents the semantic relatedness of two portions of text. This coefficient is derived from the co-occurrence of the words within a set of large text corpora. In the current study, coefficients were generated between 1) the consistent sentence and target sentence, and 2) the inconsistent sentence and target sentence. The difference between these two coefficients were calculated, and topics that had equivalent or near equivalent difference scores were paired. To make the first list, one topic from each pair was randomly selected to be consistent or inconsistent. The paired topic was therefore the opposite. For the other list, the consistency of the topics was reversed. By pairing the topics, the differences in the level of semantic relatedness between the manipulated sentence and the target sentence calculated above was equivalent between the first group of texts (M = .01, SD = .03) and the group of texts they were paired with (M = .01, SD = .04).

Within each passage, the introduction and the start of the causal chain provided a short introduction to the topic followed by a description of the causal events leading up to target event. It included a prior knowledge sentence that presented information necessary to understand the elements that connect the consistent or inconsistent sentence with the target sentence. In one example, the sentence "*This broken down nectar and water is regurgitated into the honey cell of the hive"* establishes that the cell contained water and broken down nectar. This allows the reader to know prior to the target sentence that water is inside the cell. This critical prior knowledge sentence was never the sentence immediately preceding the manipulated event sentence. In this example, there was one sentence ("The bees begin to move their muscles.") intervening. On average, the introduction section was 6-7 sentences long, with 4 causal elements and 1-2 sentences intervening between the prior knowledge sentence and the manipulated event sentence.

There were two versions of the manipulated event sentence: consistent and inconsistent versions. Consistency was manipulated by modifying one sentence to express a phrase (e.g., warms/cools) that was either conceptually consistent or inconsistent with the target sentence (e.g. the water as being heated). The conflict will become apparent if the reader attempts to connect the two inconsistent events together. There were no words overlapping between the manipulated event sentence and the target sentence. There was one overlapping noun phrase between the prior knowledge sentence and the manipulated event sentence (e.g., honey cell) and a different overlapping noun phrase between the target sentence (e.g., water). All target sentences were 14 syllables in length. The full set of texts are located in Appendix A.

Task Instructions

Two different reading tasks were created to manipulate the way readers processed the explanations. The instructions can be found in Appendix B. The read-to-understand task asked readers to read to understand each scientific explanation:

> "You will be reading several texts about different scientific processes. Each passage presents an explanation for a different scientific phenomenon (e.g., how lightning forms, how digestion works). Please read to understand each explanation for how each scientific process occurs. Later on, you will be answering questions about the texts that you read."

In contrast, the structure-and-strategy task described the structure of an explanation and instructed students to self-explain as they read, in order to connect the events together and to check that everything makes sense (Chi et al., 1989; McNamara, 2004):

> "You will be reading several texts about different scientific processes. Each passage presents an explanation for a different scientific phenomenon (e.g., how lightning forms, how digestion works).
> An explanation in science is a detailed series of causal statements that leads from an initial event to an outcome event. For instance, understanding how the sugar in soda (initial event) leads to obesity (outcome event) means learning about how physiological mechanisms such as ingesting sugar changes one's metabolic rate and hunger level, and how they relate to each other.
> While you are reading, you should explain to yourself how the earlier events in the text cause each new event. To do so, you should check to make sure you understand what causes each event to bring about the next event. You should also regularly check that the connections between the events logically make sense.
> Later on, you will be answering questions about the texts that you read."

Procedure

The texts were presented on a computer using E-PRIME, a software package that presents stimuli and records responses (Schneider, Eschman, & Zuccolotto, 2002). Participants were trained to use the program and read a short example passage. After training, participants were randomly assigned to one of the task instructions and one of the experimental text lists. After reading the task instructions, participants completed the task comprehension check to ensure that readers had read and understood the reading task (See Appendix B). The check included the reading instructions, with seven words omitted that needed to be filled in. The omitted words were chosen based on their importance for understanding the assigned reading task. Readers were allowed to return to the original reading task to identify the missing words, if necessary.

Participants then read the experimental texts, which were presented in a random order. Before each new text, participants saw the word “READY” for 750 milliseconds. Following the methodology of past research, the texts were then read one sentence at a time at the participants own pace (Long & Chong, 2001; Singer, 1993; Wiley & Myers, 2003). The texts were read using a self-paced moving window format, where only one sentence was presented on the screen at a time. Participants progressed to the next sentence by hitting the spacebar, and E-PRIME automatically recorded the reading time for each sentence at millisecond accuracy.

CHAPTER 10

RESULTS AND DISCUSSION

Target reading times were divided by the number of syllables in the sentence. However, due to a programming error, participants read 8 inconsistent texts and 4 consistent texts rather than 6 inconsistent and 6 consistent. To ensure that none of the differences were driven by one or two texts, the 8 inconsistent texts were randomly split into 2 groups – group A and group B. Therefore, three means were computed for each participant: consistent, inconsistent (A), inconsistent (B).

The means were submitted to a 2 (Task: understand vs structure-plus-explanation) by 3 (Consistency: consistent vs inconsistent A vs inconsistent B) mixed ANOVA with Task as the between-participants factor. The mean reading times can be found in Table 2. A significant interaction of Task and Text Consistency on reading time was found $F(2, 172) = 3.134$, $p = .046$, $\eta^2 = .009$. For the Read-to-Understand task, no statistically significant differences in target reading time were found between the consistent and inconsistent condition, $F(2, 80) = 1.33$, $p = .270$. In contrast, for the Structure-and-Strategy task, there was a difference, $F(2, 92) = 3.16$, $p = .047$. Follow-up tests indicated that the two groups of inconsistent passages did not differ from each other, but were read significantly longer than the consistent passages. Because the two inconsistent versions had near identical reading times, they are collapsed in Table 2.

Table 2

Means and Standard Deviations for Target Reading Times (Msec/syllable) across each condition.

	Consistent	Inconsistent
Read-to-Understand	320.76 (194.09)	303.64 (159.35)
Structure-and-Strategy	265.34 (157.43)	295.09 (203.64)

The results suggest that participants noticed the inconsistency only when instructed about explanation structure and given a strategy to understand the texts. The fact that there was no difference when instructed to "read to understand" suggests that the breaks were fairly difficult to notice. However, the fact that the difference occurred for participants in the Structure-and-Strategy condition indicates that the passages were sensitive to task manipulations. Yet it is unclear whether this finding was due to the describing explanation structures, or to the self-explanation instructions or to a combination of both.

CHAPTER 11

PRIMARY EXPERIMENT

The aim of the current experiment was to replicate the findings from the pilot and to investigate whether presenting the structure component of the structure-and-strategy task in isolation would be enough to help readers detect coherence breaks. Additionally, the study examined the impact of reading skill level on the detection of coherence breaks.

Methods

Participants

One-hundred and three psychology students (mean age = 19.15, *SD* = 1.33, 58% female) from Northern Illinois University participated for course credit. The participants came from two lower-division undergraduate psychology courses, Introduction to Psychology, and Lifespan Development. The demographics were 55% white, 18% Hispanic, 14% African American, 1% Asian American, 1% American Indian or Alaska Native, and 11% other or mixed ethnicity. The Institutional Review Board at Northern Illinois University approved all procedures.

Design

The study was a 2 x 3 x 2 design, varying Text Consistency (consistent vs. inconsistent) as a within-subjects variable, and Task (read-to-understand vs. structure-only vs. structure-and-strategy) and Reading Skill as between-subjects variables. Additionally, a List variable (List A vs. List B) was created to counterbalance the consistency of the texts.

Due to a limited number of available participants, both individual components of the structure-and-strategy task could not be included in the design. By including only one of the components, the structure-and-strategy task could still be included in the design to see if the results from the pilot would replicate. Using the 3 tasks would still allow some initial conclusions to be drawn about the unique influence of the structure instructions on comprehension. If the Structure-and-Strategy condition leads to detection but the Structure-only and Read-to-Understand conditions do not, it would suggest that the strategy instructions are most important. If in contrast the Structure-and-Strategy and Structure-only conditions both show signs of detection but the Read-to-Understand condition does not, it would suggest that structure instructions are important but that strategy instructions either have no effect or are redundant with the structure instructions.

Materials

Texts

The texts were the same 12 used in the pilot study.

Task Instructions

The Read-to-Understand task and Structure-and-Strategy task were the same instructions used in the pilot study. A Structure-only task was created by extracting the explanation structure description from the Structure-and-Strategy task, as can be seen below. The formatted task and task comprehension check can be found in Appendix B.

> You will be reading several texts about different scientific processes. Each passage presents an explanation for a different scientific phenomenon (e.g., how lightning forms, how digestion works).
> An explanation in science is a detailed series of causal statements that leads from an initial event to an outcome event. For instance, understanding how the sugar in soda (initial event) leads to obesity (outcome event) means learning about how physiological mechanisms such as ingesting sugar changes one's metabolic rate and hunger level, and how they relate to each other.
> Please read to understand each explanation for how each scientific process occurs. Later on, you will be answering questions about the texts that you read.

Conflict Detection Task

A conflict detection task was developed to assess the explicit detection of the inconsistent statements. Instructions and sentences used can be found in Appendix C. Participants were asked to "rate how inconsistent any part of this sentence is with any of the information from each text you read" on a 6-point Likert-type scale, with 1 being consistent and 6 being inconsistent. The instructions included a practice item and feedback on the practice to ensure that readers understood how the inconsistencies could have manifested within the texts, so they would report whether they had detected any of these types of inconsistencies while reading. Then, participants were given the 12 items for the experimental passages. Each item began with the topic (e.g., honey) followed by the target sentence for that passage. The items were presented in a random order in E-Prime. Half of the items were consistent and half were inconsistent for each participant.

Reading Skill

Performance on the reading portion of the ACT was used as a proxy for reading skill. The informed consent included a line for participants to sign if they wanted to provide permission to obtain their ACT scores. Of the 129 participants that completed the study, 103 of the participants gave consent to retrieve their ACT scores. The mean ACT reading score was 22.78 ($SD = 4.81$), with a median score of 23. The scores ranged from 12 to 35. The scores followed a normal distribution, with about the same the number of low scores (20 participants at or below 18) and high scores (17 participants above 27).

Scientific Explanation Question

A short answer question was created to examine participants' knowledge about explanation quality. The question can be found in Appendix D. The question asked participants to explain what they would look for in an explanation in order to fully understand the phenomenon being described.

Final Survey

A final survey asked participants about their interest in science and the topics they read about, and assessed the number of science classes taken during high school and college.

Additionally, this survey asked participants for demographic information. This survey can be found in Appendix E.

Procedure

Participants were randomly assigned to one of the task instructions and to one of the experimental text lists. The procedure was the same as in the pilot (practice with E-PRIME, reading the task instructions, complete task comprehension check, read experimental texts sentence at a time). After reading, participants completed the conflict detection questions within E-PRIME. Participants then completed paper-and-pencil versions of the scientific explanation quality question and final survey before being debriefed and thanked for their time.

Data Preparation

Reading Times

Reading times were examined for both the target sentence and the sentence immediately following the target, termed the "spill-over" sentence. This second sentence was analyzed in order to capture any delayed effects that would still indicate detection of a coherence break. Sentence reading times were derived by dividing the number of milliseconds by the number of syllables in the sentence. The target sentences all contained 14 syllables. The number of syllables in the spill-over sentence varied from 9 to 16 syllables (*M* = 13.75, *SD* = 2.42). Target sentence reading times that were more than 3 standard deviations from the participant's average reading time were excluded from the analysis. In addition, a minimum reading time of 50 milliseconds per syllable was used to ensure that readers were not spending too little time reading each sentence (corresponding to a little less of a second on the target sentence). Therefore, any target sentence reading times less than 50 milliseconds per syllable were also excluded. This set of criteria resulted in the exclusion of less than 1% of the data.

Conflict Detection Ratings

Ratings on the conflict detection questions were analyzed both as a continuous variable and as a dichotomous variable which was required for the d-prime detection scores. For the d-prime score, responses from 1 to 3 were designated a "consistent" response, and 4 to 6 were designated an "inconsistent" response. "Hits" were calculated by summing the number of inconsistent target sentences that were correctly identified as inconsistent, out of a possible six sentences. "False Alarms" were calculated by summing the number of consistent target sentences that were incorrectly identified as inconsistent, out of a possible six sentences. The hits and false alarms were standardized, and a d-prime score was derived from the difference between the standardized hits score and the standardized false alarms score. Explicit detection would be indicated by a positive d-prime score The mean of the d-prime scores was -.0073 (*SD* = 1.33), with scores ranging from -4.06 to 3.11. Only 21.4% of the participants had d-prime scores above 1. This analysis suggests that participants had very low explicit detection.

CHAPTER 12

RESULTS

Reading times were analyzed with mixed-effects modeling using the *lme4* package in R (Bates, Maechler, & Dai, 2007). Significance tests were done using an alpha level of .10 using a one-tailed test, unless otherwise noted. One-tailed tests are warranted because the predicted directions were based on the findings of prior research, admittedly some of which were conducted using narrative text. In the analysis, Participants and Texts were both added as random factors. The fixed factors were Text Consistency (consistent vs. inconsistent) and Task (read-to-understand vs. structure-only vs. structure-and-strategy), and the Text Consistency x Task interaction. List (list A vs. list B) and Class (Introduction, Lifespan Development) were also included as fixed factors to partial out any variance accounted for by these variables. Contrasts for the Task variable were created to compare a) the Read-to-Understand task to the Structure-only task, and b) the Read-to-Understand task to the Structure-and-Strategy task. For each set of analyses, the variables were entered hierarchically.

Research Question 1: Do Readers Spontaneously Detect Coherence Breaks Within Scientific Explanations as Measured by Reading Times (Implicit Detection)?

Target Sentence

The baseline model included only the intercept and the two random factors (participants and texts). The first model added List, and the second list added Class. The third model added Text Consistency. The analysis revealed that the third model accounted for a significant amount of additional variance beyond the baseline model. Text Consistency was a significant predictor of reading time $t(1108) = 1.94$, $p = .053$, $r = .058$. Target sentence reading times were significantly longer for the inconsistent passages ($M = 285.45$, $SD = 174.71$) than the consistent passages ($M = 269.47$, $SD = 162.53$).

Spill-over Sentence

As with the target sentence analysis, the baseline model included only the intercept and the two random factors (participants and texts). The first model added List, and the second list added Class. The third model added Text Consistency. None of the models accounted for a significant amount of variance above the baseline model.

Research Question 2: Does Either Reading Skill or Task Instructions Influence Implicit Detection?

Target Sentence

For target sentence analysis, the baseline model included only the intercept and the two random factors. The first model added List, and the second list added Class. The third model added Text Consistency. The fourth model added Reading Skill. The fifth model added Task. The sixth model included the Text Consistency X Reading Skill interaction, the seventh model included the Text Consistency x Task interaction, and the eighth model included the Reading Skill x Task interaction. The ninth and final model included the 3-way interaction of Text Consistency x Reading Skill x Task. The means and standard errors can be found in Table 3. Only the third model that included Text Consistency was significant. No other models accounted for a significant amount of additional variance.[2][3]

Spill-over Sentence

The baseline model included only the intercept and the two random factors. The first model added List, and the second list added Class. The third model added Text Consistency. The

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[2] The same analysis was carried out including the data from participants who we did not have ACT scores for, or who did not allow access to their scores. The results were replicated using this larger data set (N = 129). The mean reading times for each task condition can be found in Table 11 in Appendix F.

[3] The same analysis was performed using scores from the science portion of the ACT as a proxy for science knowledge. The results were no different from the results presented with ACT scores from the reading portion. The mean reading times for high science knowledge and low science knowledge participants can be found in Table 12 in Appendix G.

fourth model added Reading Skill. The fifth model added Task. The sixth model included the Text Consistency X Reading Skill interaction, the seventh model included the Text Consistency x Task interaction, and the eighth model included the Reading Skill x Task interaction. The ninth and final model included the 3-way interaction of Text Consistency x Reading Skill x Task. The means and standard errors can be found in Table 4. The ninth model accounted for a significant accounted for a significant amount of additional variance above the other models. A significant 3-way interaction of Text Consistency, Task, and Reading Skill was found, $b = 12.37$, $t(1103.40) = 2.64$, $p = .008$ $r = .079$. Follow-up analyses examined reading time differences for the Read-to-Understand and Structure-only tasks separately. These analyses revealed that there were no reading time differences between the consistent and inconsistent passage reading times, tested 1 standard deviation above and below the mean ACT reading score. This result held for both task conditions. Therefore, the significant result did not provide any meaningful results that indicated a boggle in reading time.

Research Question 3: Do Implicit and Explicit Detection Measures Converge?

Mixed-effects modeling was used to examine the ratings on the conflict detection questions. The baseline model included only the intercept and the two random factors. The first model added List, and the second list added Class. The third model added Text Consistency. The fourth model added Reading Skill. The fifth model added Task. The sixth model included the Text Consistency X Reading Skill interaction, the seventh model included the Text Consistency x Task interaction, and the eighth model included the Reading Skill x Task interaction. The ninth and final model included the 3-way interaction of Text Consistency x Reading Skill x Task.

Table 3

Means and Standard Errors for Target Reading Times across Text Consistency and Task, 1 standard deviation above and below the mean of ACT reading score, in msec/syl.

	Read-to-Understand		Structure-only		Structure-and-Strategy	
	Consistent	Inconsistent	Consistent	Inconsistent	Consistent	Inconsistent
Less-skilled (1 SD below mean)	277.60 (23.77)	282.56 (25.55)	319.68 (26.06)	344.38 (32.68)	261.05 (22.86)	267.71 (22.01)
More-skilled (1 SD above mean)	243.69 (27.37)	266.16 (29.86)	252.44 (24.32)	283.53 (30.00)	265.88 (31.52)	277.24 (20.67)

Table 4

Means and Standard Errors for Target Reading Times across Text Consistency and Task, 1 standard deviation above and below the mean of ACT reading score, in msec/syl.

	Read-to-Understand		Structure-only		Structure-and-Strategy	
	Consistent	Inconsistent	Consistent	Inconsistent	Consistent	Inconsistent
Less-skilled (1 SD below mean)	302.89 (31.68)	295.01 (22.05)	352.13 (30.99)	309.78 (30.13)	270.14 (33.68)	259.75 (29.71)
More-skilled (1 SD above mean)	288.03 (36.16)	251.26 (24.58)	258.82 (28.70)	289.79 (28.13)	294.02 (31.96)	292.94 (28.28)

Table 5

Means and Standard Errors for Target Reading Times across Text Consistency and Task, 1 standard deviation above and below the mean of ACT reading score, in msec/syl.

	Read-to-Understand		Structure-only		Structure-and-Strategy	
	Consistent	Inconsistent	Consistent	Inconsistent	Consistent	Inconsistent
Less-skilled (1 SD below mean)	2.76 (.18)	2.76 (.18)	2.60 (.25)	2.86 (.22)	2.99 (.28)	2.81 (.19)
More-skilled (1 SD above mean)	2.58 (.25)	2.58 (.21)	2.70 (.24)	2.94 (.21)	2.81 (.27)	3.18 (.18)

The means and standard errors can be found in Table 5. Model seven accounted for a significant additional amount of variance above the other models, and no other models beyond model seven were significant. To understand the nature of the Text Consistency and Task interaction found in model seven, the "inconsistency" effect for the Read-to-Understand condition was compared to the other two task conditions using planned contrasts. The contrast between the Read-to-Understand task and Structure-only task was significant (b = .614, t(1118) = 2.61, p = .001, r = .078), as was the contrast between the Read-to-Understand task and Structure-and-Strategy task (b = .469, t(1118) = 2.09, p = .037, r = .062). Counter-intuitively, the participants given the Read-to-Understand task reported the consistent passages (M = 3.06, SD = .24) as significantly more inconsistent than the consistent passages (M = 2.67, SD = .20). The ratings between the consistent and inconsistent passages did not vary significantly for either the Structure-only task or the Structure-and-Strategy task.

To address the research question as to whether the reading times (an implicit measure) would converge with the explicit measure, the relationship between reading times and conflict detection responses was analyzed using correlations. A reading time detection score was derived for each participant by subtracting the mean of the inconsistent target sentence reading times from the mean of the consistent sentence target reading times, as shown below.

$$RT_{\text{detection score}} = RT_{\text{inconsistent target}} - RT_{\text{consistent target}}$$

This score was then correlated with the d-prime for the conflict detection questions and ACT reading score. The correlations can be found in Table 6. No significant relationships were found between the reading time detection score and d-prime, or between either of these scores and ACT reading score.

Table 6

Correlations between ACT reading score, $RT_{detection\ score,}$ and d' (conflict detection score)

	ACT reading	$RT_{detection\ score}$	d'
ACT reading	1		
$RT_{detection\ score}$	.093	1	
d'	.130	.137	1

*Correlation is significant at .05 level
**Correlation is significant at .01 level

To examine whether there was any influence of task, these correlations were computed for each task separately. The correlations for the Read-to-Understand task can be found in Table 7. No significant relationships were found between the reading time detection score and d-prime, or between either of these scores and ACT reading score.

Table 7

Correlations between ACT reading score, $RT_{detection\ score,}$ and d' (conflict detection score) for the Read-to-Understand task condition.

	ACT reading	$RT_{detection\ score}$	d'
ACT reading	1		
$RT_{detection\ score}$	.134	1	
d'	.144	.226	1

*Correlation is significant at .05 level
**Correlation is significant at .01 level

The correlations for the Structure-only task can be found in Table 8. No significant relationships were found between the reading time detection score and d-prime, or between either of these scores and ACT reading score.

Table 8

Correlations between ACT reading score, $RT_{detection\ score}$, and d' (conflict detection score) for the Structure-only task condition.

	ACT reading	$RT_{detection\ score}$	d'
ACT reading	1		
$RT_{detection\ score}$	.072	1	
d'	.002	-.007	1

*Correlation is significant at .05 level
**Correlation is significant at .01 level

The correlations for the Structure-and-Strategy task can be found in Table 9. No significant relationships were found between the reading time detection score and d-prime, or between either of these scores and ACT reading score.

Table 9

Correlations between ACT reading score, $RT_{detection\ score}$, and d' (conflict detection score) for the Structure-and-Strategy task condition.

	ACT reading	$RT_{detection\ score}$	d'
ACT reading	1		
$RT_{detection\ score}$	.057	1	
d'	.237	.176	1

*Correlation is significant at .05 level
**Correlation is significant at .01 level

CHAPTER 6

GENERAL DISCUSSION

Understanding how people comprehend scientific texts is important in STEM education and the progress of our society (Achieve, 2015). Explanations are particularly important for science as they provide accounts of the mechanisms that bring about scientific phenomena. The goal of the current dissertation therefore was to examine (1) whether readers spontaneously implicitly detect coherence breaks within scientific explanations, (2) whether implicit detection depends on reading skill or task instructions, and (3) whether implicit and explicit detection measures converge.

Research Question 1: Do Readers Spontaneously Detect Coherence Breaks Within Scientific Explanations as Measured by Reading Times (Implicit Detection)?

Concerning Research Question 1, reading time results revealed that participants took longer to read the target sentences within the inconsistent passages than the consistent passages. Readers therefore appear to be spontaneously detecting the coherence break created by the inconsistency. These findings appear to support the *Mental Model Hypothesis*. This finding is noteworthy because although prior research on scientific texts had found evidence that readers detect coherence breaks, the evidence was somewhat less direct in that they focused on bridging inferences. In the current experiment, we found more direct evidence that readers detect coherence breaks by using a methodology specifically designed for that purpose.

The boggle in reading time, however, may have arisen at the surface structure between the conflicting meanings of the words (e.g., cooled vs. heated) rather than at the situation model between the meanings of the two events. The opposite words would presumably affect the integration of the sentences according to Kintsch's CI model, and hence reading times. This interpretation is supported by the lack of differences by reading skill or task instruction conditions and by the lack of converging evidence from explicit detection. This reasoning is elaborated in the discussion of Research Question 2.

Research Question 2: Does Either Reading Skill or Task Instructions Influence Implicit Detection?

Reading Skill

In regards to Research Question 2, no target reading time differences were found for reading skill. This result fails to support the *Reading Skill Coherence Sensitivity Hypothesis*, which predicted that more-skilled readers, but not less-skilled readers, would show longer target sentence reading times for the inconsistent passages than consistent passages. These results do not replicate past research showing that more-skilled readers appear to be more sensitive to changes in causal coherence than less-skilled readers (Todaro et al., 2010; Wittwer & Ihme, 2014). Therefore, more-skilled readers should have been more likely to detect the breaks in causal coherence than less-skilled readers. However, there was no difference due to reading skill in the current experiment. The null effect of reading skill may suggest that the difference in reading time between consistent and inconsistent versions was caused by something other than the causal coherence break between the conflicting events. Instead, it is possible that the difference in inconsistent and consistent target sentence reading times was caused by the conflicting word meanings as was mentioned earlier. This is consistent with research using narrative texts which found that both less-skilled and more-skilled readers spontaneously detect semantic coherence breaks that occur in adjacent sentences (Long & Chong, 2001). It is important to note, however, that this past research on reading ability differences did not use science texts (Long & Chong, 2001; Todaro et al., 2010), and used different measures to examine the detection of coherence breaks (Todaro et al., 2010; Wittwer & Ihme, 2014). Still, that reading skill did not interact with consistency could suggest that understanding scientific explanations is particularly challenging for all readers, and as a result, readers only detect shallow semantic coherence breaks rather than deeper causal coherence breaks.

There were also no differences when the analysis was run using the scores from the science subset of the ACT, which acted as a proxy for science knowledge. However, these null results may have arisen because the ACT science portion mainly assesses knowledge of the structure of scientific texts and not how to process explanations. For example, items measure whether the reader could identify hypotheses or evidence from the test passages. Therefore, this assessment may not have captured knowledge for how to process explanations, which is essential for detecting coherence breaks between the events of an explanation.

A related reason for the lack of effect of reading skill is that the ACT measures are not sensitive to how readers allocated attentional resources to the component processes involved in comprehension. The detection of causal coherence breaks requires readers to allocate adequate resources to the integration of information while reading. If readers do not attempt to integrate concepts, they will fail to detect that a coherence break has occurred (Long & Chong, 2001; Morishima, 2013). Research has found that less-skilled readers have difficulty allocating cognitive resources properly while reading (Bell & Perfetti, 1994). Therefore, a measure that captures how readers are allotting resources during comprehension could have provided a more sensitive measure of reading skill than ACT scores. Although the ACT measured reading comprehension at some level, it is possible that they did not measure comprehension at the level needed to detect the inconsistencies.

An additional issue of using ACT scores is that they created a selection bias, as participants could opt out of providing a score. Furthermore, some participants probably did not take the ACT before college. This bias could have excluded a potentially meaningful group of individuals from the analysis. For example, lower-scoring individuals may not want their ACT scores to be known to the experimenters. Therefore, a measure that is sensitive to resource allocation and that can be administered as part of the experiment could avoid selection bias issues and potentially reveal reading skill differences that were not found in the current study.

Task Instructions

Similar to the results for reading skill, there were also no target reading time differences between the different task instructions. This result failed to support the *Task Model Hypothesis*, that the Structure-only and Structure-and-Strategy task conditions would implicitly detect the break in causal coherence, but the Read-to-Understand task condition would not. This finding is surprising as it did not replicate the results from the pilot study. However, the task differences that were found in the pilot study may have been due to the programming error that occurred. The error was that participants saw many more instances of inconsistent passages than consistent passages. This in itself would make inconstancies somewhat salient. It is possible that because of the increased number of inconsistent tasks, coupled with the Structure-and-Strategy task was enough to account for the interaction in the pilot study. When this problem was corrected in the main study, the influence of the unbalanced list was removed the interaction was removed as well.

In addition to the target sentence analysis, the spill-over sentence was analyzed in order to capture any delayed detection of the coherence break. Delayed responses to coherence breaks have been found when sentences share limited semantic relations (Cook & O'Brien, 2014). The analysis revealed a significant interaction of Task, Reading Skill, and Text consistency. This finding was largely counter-intuitive given that most of the data showed longer times in the consistent conditions. Also, the spill-over sentence was not as controlled as the target sentence. Therefore, it is difficult to interpret the findings at the present time.

One reason why the Structure-only and Structure-and-Strategy tasks might not have had an effect in the main study is that participants encoded but did not apply the instructions during reading. Support for this notion comes from an analysis of the task comprehension check and scientific explanation question. An examination of the task comprehension check shows that readers were at least encoding the instructions that they were given. The scientific explanation was therefore analyzed to see if they applied the instructions during reading. Recall that the scientific explanation question asked participants to report what is important to pay attention to while reading explanations. Therefore, the information within the Structure-only and Structure-and-Strategy tasks could have been used to answer this question. The protocols were coded using the critical details of the task instructions that fell within three categories: explanation structure (e.g., understand how the events are connected), specific reading strategy (i.e., visualize, think logically about events), and general reading strategy (e.g., pay attention to details). A second rater coded 20% of the data, and inter-rater reliability was good ($\kappa = .61$). No differences were found on the proportion of participants mentioning each of these categories across the three task conditions. In fact, the proportion of explanation structure and specific reading strategy mentions was quite low, with a higher proportion of general reading strategy mentions being made on average (see Table 10). The proportions for explanation structure were approximately 8% higher in the Structure-only and Structure-and-Strategy conditions than in the Read-for-Understanding condition, but the difference was not significant.

Table 10

Proportion of explanation structure, general reading strategy, or specific reading strategy productions in the scientific explanation question.

	Explanation Structure	Specific Reading Strategy	General Reading Strategy
Read-for-Understanding	13.57% (.14)	11.43% (.18)	75.29% (.44)
Structure-only	21.00% (.19)	10.75% (.20)	64.52% (.49)
Structure-and-Strategy	22.30% (.22)	10.00% (.19)	70.27% (.46)

It therefore seems as though readers may not have been trying to apply the task or did not know how to apply the task while reading. One might use this data to reassign participants to task condition based on their answers rather than the instructions in which they were given, but it is likely that more participants would be needed to make the results meaningful.

These lack of reading time differences across task conditions also support the notion that readers were detecting a conflict at the surface structure rather than the situation model. If the Structure-only or Structure-and-Strategy tasks led to the building of a passage representation at the situation model level, readers given these tasks would have been more likely to notice the causal coherence break and explicitly detect the problem within the text. However, none of the detection rates across the different tasks were at ceiling, and they were roughly equal. The Read-to-Understand condition only detected 28% of the inconsistencies, the Structure-only condition detected 36%, and the Structure-and-Strategy condition detected 35% of the inconsistencies. These detection rates are higher than the ones found by Yeagle et al. (2015), who reported an explicit detection rate of 15% when readers were not given a warning of issues within the text, and 30% when a warning was given. Still, there is quite a bit of space to increase the explicit detection of issues within a text. Taking the implicit detection and explicit detection results together, it appears that simple instructions about of the structure of an explanation and strategies for processing are not sufficient to help readers spontaneously detect coherence breaks. Readers may instead require a detailed tutorial and practice reading explanations in order to change how they process these texts (see Kopp, 2013).

The possibility that readers are only processing at a shallow semantic level is consistent with other research that has found readers have difficulty detecting anomalies in text (Barton & Sanford, 1993; Daneman, Lennertz, & Hannon, 2007; Glenberg, Wilkinson, & Epstein, 1982). For instance, Barton and Sanford (1993) presented participants with short passages that asked "When an airplane crashes, where are the survivors buried?". This question contains an anomaly, as the survivors of a plane crash would not need to be buried. They found that readers frequently failed to identify the anomaly, and that detection was contingent upon the phrasing of the question. When the noun fit with the meaning of the rest of the passage (e.g., injured, surviving dead), participants were highly unlikely to report noticing the anomaly. Barton and Sanford concluded that readers will not perform a deeper analysis of the content of a text when they can generate simple connections between sentences while reading. Similarly, while reading explanations readers may only attempt to establish simple relationships (e.g., between word meanings) rather than attempting to carefully process information, which could explain why readers did not appear to detect the deeper causal breaks in coherence.

Research Question 3: Do Implicit and Explicit Detection Measures Converge?

The analysis of the ratings on the conflict detection questions revealed a significant interaction of Text Consistency and Task. Follow-up analyses determined that this result was driven by the consistent texts being rated as significantly more inconsistent than the inconsistent texts by participants given the Read-To-Understand task. This result is surprising and counterintuitive, as the texts were created to ensure that the target sentence did not conflict with any other information from the text in the consistent versions. Therefore, the exact reason why this effect emerged is unclear. Still, this result does not indicate that the participants were explicitly detecting the coherence breaks within the texts.

At the heart of the research question is whether explicit and implicit measure converge. The answer is no; there were no significant relationships between implicit detection using reading times and explicit detection using the conflict detection questions. This result held across each of the task conditions. It appears then that noticing a problem while reading does not guarantee that the reader will become consciously aware of the problem or remember the problem once it happened. These findings do not support the *Mental Model Construction Hypothesis*, which predicted a relationship between measures of implicit detection and explicit detection. These results suggest that the relationship between implicit detection and explicit detection is complex and requires further understanding.

The relationship between the constructs of implicit detection and explicit detection is complex because of the many behavioral responses that the reader can do in response to a coherence break (Baker, 1985a; Chin & Brewer, 1993; Stadtler & Bromme, 2014). One response is to hold the conflict in abeyance if the inconsistency is perceived as resolvable using external resources (Chinn & Brewer, 1992, 1993). For example, after encountering a problem in a text, readers may choose to seek out another text or article that could clarify or resolve the issue. The reader would therefore hold the inconsistency in abeyance (Chinn & Brewer, 1998). This response is likely more prevalent while reading scientific or other types of expository texts, because people have little background knowledge about scientific topics, which could lead readers to think that other existing knowledge would clarify the apparent problem. Therefore, the reader may assume that there is some true or agreed upon answer that can be used to clarify the problem in the text they read.

Another response to a coherence break is to consider source information, if it is available (Stadtler & Bromme, 2014). Source information refers to aspects of the author, including credentials, publication outlet, and year of publication (Britt & Aglinskas, 2002). By linking a discrepancy to its respective source, both statements can be simultaneously represented in the reader's mental representation (Perfetti, Rouet, & Britt, 1999; Britt & Rouet, 2012). Research has shown, however, that lay readers often fail to consider source information while reading (Britt & Aglinskas, 2002; Steffens, Britt, Braasch, Strømsø, & Bråten, 2014; Winburg, 1991). As a result, they may only consider source information when there is a very salient discrepancy between two agents (Braasch et al., 2012).

Another possible response to detecting a coherence break is to "fix" the coherence break. For example, readers could also generate an inference that repairs the coherence break (Stadtler & Bromme, 2014). In the present passages, they may have inferred an intervening event or state that would make the inconsistent versions coherent. For instance, within the inconsistent version of the sweat text, production within the sweat glands decreases, but a large amount of sweat is released onto the skin. The reader could spontaneously infer that the sweat glands already contained a large amount of sweat before production decreased. This inference would make the sentences consistent and the discrepancy within the text would go unnoticed. Research using reading times (Singer & Gagnon, 1999; Wiley & Myers), post-reading questions (Otero & Campanario, 1990), think-alouds (Blanc, Kendeou, van den Broek, & Brouillet, 2008), recall data (Hakala & O'Brien, 1995; Otero & Kintch, 1992), and summaries (Rouet, Le Bigot, de Pereyra, & Britt, 2016) have all found evidence for inferences to reestablish coherence.

Readers can also examine other portions of the text in response to a coherence break (Baker, 1979; Baker & Anderson, 1982). For example, Clark et al. (1988) found readers performed more regressions to prior text information after reading an inconsistent statement than when the passages were consistent. These regressions suggest that readers were attempting to verify the presence of an inconsistency, or were searching for information that could account for the discrepancy. Similarly, readers may process the statements following the inconsistency in an attempt to identify an explanation for the conflict (Baker, 1979). These behaviors are analogous to abeyance (Chinn & Brewer, 1992, 1993, 1998), as the anomalous information is not addressed until further information is gathered. In the current study however, the self-paced moving window format prevented readers from returning to any earlier portions of the text.

In the context of the different behavioral responses readers can have to a coherence break, the current results do not disconfirm the *Mental Model Construction Hypothesis.* Instead, explicit detection is therefore just one potential outcome after implicitly detecting a coherence break. The lack of a relationship found in the current study does not mean that readers will always fail to explicitly detect that an issue is present. More research is needed to better understand the factors that drives a reader to perform one of these reparative action over another.

Beyond the reader's behavioral responses, explicit detection of the inconsistency could have been influenced by the reader's expectations about the texts. Participants could have believed that the information that they were provided was complete and accurate, which is consistent with Grice's maxim of quality that assumes people are truthful (Grice, 1975). Therefore, they may not have expected the content to be inconsistent and failed to read carefully. This notion could have been reinforced by the tasks, which described the passages as presenting explanations for a scientific phenomenon. This wording could have implied that the texts presented the accepted explanation for each phenomenon in the respective scientific field. Although readers still had the ability to detect the coherence breaks within the explanations, such expectations could have influenced any decisions during reading about whether or not the text contained a problem. Future research may manipulate expectations in the context of detecting inconsistencies in scientific explanations. One method similar to the pilot study would be to increase the ratio of inconsistent passages to consistent passages, which could increase the salience of the inconsistencies. Changing this ratio might not be pragmatic, however, as readers may not regularly encounter as many inconsistencies in everyday situations, which would prevent the conflicts from becoming more salient to the reader. Instead, a more practical option would be to provide the reader with a task that includes a goal to evaluate the inconsistent details. For instance, readers could be asked to screen news stories before they are sent to the editor for publication (de Pereyra, Britt, Braasch, & Rouet, 2014). Such a task could prompt readers to scrutinize the content of each story, and therefore make the inconsistencies more apparent.

Instructional Implications

The reading time findings add to research on science text comprehension by capturing moment-to-moment processes critical for the construction of a coherent passage representation for an explanation. From these results, it appears that readers do not spontaneously attempt to construct a passage representation that includes the deeper causal relationships between the events of the explanation. Instead, they appear to build a passage representation using shallow semantic connections. Building such a representation is problematic because breaks in causal coherence created by problems or missing events would go unnoticed by the reader. These problems would therefore remain unresolved, and the resulting passage representation for the explanation would be either incomplete or inaccurate.

Failing to represent the causal relationships between events could also become problematic in circumstances where students are required to think of solutions to problems that involve explanations. In these situations, students need to consider changes that can be made to a causal chain and the consequences of those changes, which requires knowledge of how each event leads to another. For example, when asked to think about solutions for the dwindling bee populations, students must understand how Varroa mites attack bees and reproduce inside the hive. With this understanding, students can start to think about how introducing a change (e.g., using pesticides, varying the temperature of the hive) could affect the rest of the process (e.g., destruction of parasite, harm to bees). If students do not represent the causal relationships of that explanation, they may have difficulty identifying key points at which changes could be made or understanding what ramifications any changes could have on the system. Therefore, the finding that readers do not appear to be attempting to establish these causal relationships while reading is a critical problem when students are learning about and applying science.

On reason students may not look for critical deeper relationships while reading is because instruction in school does not strongly emphasize the need to identify and represent these connections. This notion is supported by research by Asiala (2014), who examined the evaluation of good and bad explanations for individuals with low and high scientific knowledge. She found that high-knowledge participants had the same difficulties evaluating scientific explanations as low-knowledge participants. Additional knowledge about science therefore does not appear to help individuals evaluate the relationships between events in an explanation. If these students were never taught to target and evaluate these relationships while reading science texts, it makes sense that they would have a similar difficulty evaluating scientific explanations as students without a scientific background.

Teachers can help students represent the critical relationships from science texts by providing students with practice identifying and evaluating these different types of connections while reading. Training could scale from identifying the relationships between simple sentence pairs to the identification and evaluation of multiple types of relationships within a passage. This training would ideally encourage the reader to actively seek out and represent the connections between concepts. Coupling this instruction with practice of behaviors such as Questioning the Author (Beck, McKeown, Kucan, & Worthy, 1996) and directed self-explanation (Wylie & Chi,

2014) could help students explicitly detect coherence breaks and avoid using repair behaviors that incorrectly fix the problem. Two tutors have already been developed that teach students about scientific explanations and how to read them, in order to improve comprehension (Jaeger, Griffin, Britt & Wiley, July 2015; Rupp, Wallace, Blaum & Britt, 2015).

Future Directions

There are a few important future research directions that could follow up on the results of the current study. One important direction would be to continue to identify conditions under which readers spontaneously detect and do not detect causal coherence breaks within science texts. The aim of the current study was to identify a few of these conditions, however none of these conditions appeared to influence detection of these coherence breaks. This finding is noteworthy in itself because the materials were designed in such a way that detection would be maximized (i.e., adjacent sentences). Still, under these conditions participants were not consistency detecting the breaks in causal coherence. Spontaneously detecting these causal coherence breaks is critical for two reasons. First, detecting these types of coherence breaks are necessary for constructing a complete passages representation for explanations (Meyer & Freedle, 1984). Second, if readers do not detect causal breaks in coherence, they will not generate the causal bridging inferences to create the complete passage representation (Noordman et al., 1992). Therefore, identifying these conditions would be valuable for helping students read explanations more effectively and ultimately represent them more accurately.

One factor that could still help readers detect causal breaks in coherence is actively engaging in instructions that they are given. Kopp (2013) found that when teaching students about arguments, some required a definition (e.g., what is a claim, what is support), whereas others required a tutorial and practice (e.g., evaluating source information). The tasks from the current study provided definitional information, but did not have the participants practice carefully reading explanations. As mentioned earlier, such a tutorial could discuss the structure of explanations in detail and provide examples that identify and elaborate upon each component. The tutorial could explain why the relationships between events is so critical for understanding how the entire process works and provide practice evaluating whether the connections between events makes sense. Such a tutorial would not only provide students with the knowledge and strategies required for checking the causal relations between events, but also help them understand why evaluating these connections while reading are so important.

As was mentioned before, two experiments have developed tutorials to help students understand scientific explanations (Jaeger et al., 2015; Wallace et al., 2016). In Jaeger et al. (2015), an experimenter used a short lesson to interactively teach high school students about how to read and understand explanations. They found that learning about a complete and coherent causal explanation for a familiar topic helped them construct better explanations from multiple documents for a different topic. Wallace et al. (2016) found similar results with a self-guided tutorial that provided explicit instruction and practice. College students given the causal chain tutorial recalled significantly more elements of the explanation from single documents like those used in this dissertation than students in the control condition. Additionally, these students correctly identified more elements in explanations when the texts were available. These studies show that tutorials can be an effective means to help students learn about scientific explanations, however they do not capture moment-to-moment construction of the passage representation for the explanations. A next step then would be to use online measure to see how these tutorials influence how these texts are read.

Besides stronger instructional manipulations, future research could also examine the influence of metacomprehension on the detection of coherence breaks within science texts. Metacomphrension refers to the reader's assessment of their own understanding of a text (Maki & McGuire, 2002). Past research has shown that when readers are encouraged to regularly check their understanding, they are able to detect and report more problems within a text than readers not given such instruction (Baker, 1984, 1985b; Hacker, 1997). When readers routinely check their understanding, it therefore appears to increase their sensitivity to breaks in coherence. Furthermore, metacomprehension has been found to only weakly correlate with reading skill (Maki & McGuire, 2002). This suggests that metacomprehension and reading skill are largely independent, and that the examination of reading skill in the current study does not give any indication of the influence of metacomprehension on the spontaneous detection of coherence breaks. As a result, it would be worthwhile to examine the impact of metacomprehension on the implicit and explicit detection of coherence breaks within science texts.

Another future direction could be directed at trying to disentangle implicit and explicit detection. That is, how can researchers identify when readers repair or ignore coherence breaks when they occur? The problem with explicit detection measures is that they typically are asked after all reading is done. But reader's memory might be too degraded to reliably measure whether they actually repaired the break during reading. The problem with asking readers earlier is that they will know that coherence breaks occur in the materials, and therefore change their reading behavior. One solution could be to ask them comprehension questions targeting the break detection. Because the question itself may "give away the answer", one might first start off with more general questions or tasks (e.g., Based on the text, describe in detail the process of making honey) progressing towards more specific questions (e.g., what does the beating of the wings do to the contents of the cell? Does the beating of the wings cool or warm the water in the honey cell?).

Another problem that arises with explicit detection is that each measure only captures one or two reparative behaviors, but not others. For instance, explicit detection questions only capture conscious awareness of the coherence break. Further questioning would determine whether readers did detect the coherence break, but chose to ignore or disregard the problem (Baker, 1979; Otero & Campanario, 1990). Recall measures have been used to capture inferences or other changes that may have been made to the passage representation (Hakala & O'Brien, 1995; Otero & Kintsch, 1992). Eye-tracking or some other reader-paced text presentation programs such as *Read&Answer* (Vidal-Abarca et al., 2011) would be required to capture regressions to earlier portions of the text. In addition, think-alouds can be used to measure explicit detection of coherence breaks. Think-alouds could be better than post-reading conflict detection questions, as readers may forget or ignore the coherence break and fail to report it later (Otero & Campanario, 1990). Think-alouds would avoid this problem by probing for detection immediately after the coherence break would have occurred. As noted in the introduction however, think-alouds may not be as sensitive to implicit detection of coherence breaks.

Research would therefore need to use a combination of these methods in order to see how these different behaviors relate to implicit detection of coherence breaks.

Other Factors and Limitations

The current findings are a valuable contribution to the study of coherence processes while reading science texts. Still, there are a few possibly influential factors that limit the current study's results. First, as was mentioned before, participants' expectations about the texts that they read could have influenced their detection of the inconsistencies. When they were presented with the inconsistent texts, they likely had no expectation that the information was incorrect. This expectation could have counteracted the instructions to read the texts carefully. It is likely however that a similar expectation arises when students are learning in a classroom. They expect that the information they are given from teachers are correct and complete unless instructed otherwise. Therefore, in that regard the findings could mimic what would occur within a classroom setting.

In addition to the readers' expectations about the texts, the time between reading and making the inconsistency judgments could have made explicit detection of the inconsistencies difficult. Participants answered the conflict detection questions after all the texts had been read. This order was chosen over asking about conflict detection after each text in order to avoid the possibility that participants would read more carefully after finding out that texts could contain problems. The trade-off however was that readers needed to identify the conflict and remember it while reading the other texts, before they were given an opportunity to report the problem. This could have limited the participants' ability to report the detection of these issues. A future study that includes think-alouds could therefore be more sensitive to the explicit detection of coherence breaks, as there would be a shorter amount of time between detection and a probe that could capture detection.

The participants' interest in the study may also have had an influence on how carefully they read the texts. While the lab setting provided a quiet and controlled environment for the study, participants may have been less motivated in this context than if the study was situated in a classroom as part of an in-class activity. In addition, participants completed the study in exchange for course credit rather than being graded on their performance on the task. Therefore, the tasks or topics may have been of little interest to the introductory psychology students, and have little to no relevance for the class for which they were completing the experiment.

Another possible influence is the complexity of the texts. It is difficult to say exactly how text complexity and difficulty accounts for the lack of explicit detection. Difficult materials may make it challenging for readers to notice these issues at the conscious level because working memory resources would be devoted to parsing and retrieving and understanding novel information. However, this depends in part on the nature of the complexity. If the complexity is based on a lack of prior knowledge, which is presumably the case here, then cognitive resources would be used up trying to identify word meanings, and construct the textbase. The situation model would suffer because of the lack of prior knowledge, and hence, the inability to notice and repair coherence breaks at the situation model level. However, if the complexity is based on awkward sentences, then the reader may be continually repairing the passage representation. In this case, they may in fact notice, repair and remember the coherence break. The current study avoided comprehension questions after each text in order to avoid superficial processing by the participants. However, including such questions could speak to whether these types of texts are particularly challenging for students.

A final limitation is the use of the self-paced moving window format. Readers saw one sentence at a time, but were not allowed to return to an earlier portion of the text. As was discussed earlier, this stops the reader from performing the repair process of rereading an earlier portion of the text as a way to resolve the coherence break or even verify that there is a problem. This might explain the low rate of explicit detection. Future research using eye-tracking software could help capture detection of the coherence break using fixation times, and also capture regressions to earlier sentences. Alternatively think-aloud protocols could capture the explicit detection of coherence breaks as well as behaviors such as rereading or intentions to read upcoming sentences in order to resolve the break.

CHAPTER 7

CONCLUSIONS

The current study's results provide some new insight into coherence processes while reading science texts by capturing online construction of the reader's passage representation. Readers appeared to only spontaneously detect coherence breaks between conflicting words (heats-cooled), but not causal coherence breaks between the events of an explanation. If the detection occurred at the event level, then there would have been evidence based on reading time skill and task instructions, which were not found. These results may suggest that readers are attempting to connect the text details at a shallow semantic level rather than at a deeper causal level. That readers are detecting the semantic coherence break is promising however, as it indicates that readers are at least attempting to connect the information from the text in some way. This provides a starting point to find ways to shift readers away from attempting to create semantic connections and to instead consider the causal relationships that are critical for comprehending scientific explanations.

The results also showed that implicit detection of a coherence break does not guarantee that readers will become consciously aware that a problem occurred while reading. Still, it is critical for students to become aware of these problems while reading science texts, as using some other reparative behavior (e.g., ignoring the problem, inferencing) could leave them with an incomplete understanding or a misconception. Becoming explicitly aware of any comprehension problems can help readers avoid these pitfalls and choose behaviors (e.g., finding an additional source) that will help them appropriately repair any problems they encounter while when learning about science. Based on these findings, the relationship between implicit and explicit detection is complex and therefore needs to be further understood.

In sum, scientific texts are difficult to comprehend, and the level understanding may not occur at the situation model, as educators would like. Understanding explanations is critical a critical aspect of a STEM education. The challenges that these types of texts present therefore make it critical for researchers to identify what processes do and do not occur while reading. Identifying these processes can provide valuable insight into new ways to help students read and learn about science in a more effective manner.

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APPENDIX A

EXPERIMENTAL TEXTS

Part of text: Title:	How Sweat Cools the Body
Introduction/ start of chain (Prior knowledge sentence in italicized):	Sweating is the body's mechanism of regulating temperature. The complete process of regulating temperature begins when our body's temperature increases. The increase in temperature activates a part of the brain called the hypothalamus. *The hypothalamus sends messages to glands that control the creation of sweat.* These messages travel throughout the body.
Manipulated event sentence (Consistent / Inconsistent version in bold):	Then there is an **increase/decrease** in production within the *glands*.
Target sentence:	The glands release a **large** amount of *sweat* onto the skin.
End of chain:	The sweat on the skin is warmed by heat given off by the body. When the sweat becomes hot enough, it evaporates. As the sweat transforms into vapor, heat from the skin is also removed. Blood in vessels near the surface of the skin is cooled. As the blood circulates, it cools the body's core.

Part of text: Title:	How Bees Make Honey
Introduction/ start of chain (Prior knowledge sentence in italicized):	Bees are like humans in that they make their own food, honey. The process of honey production starts by worker bees seeking out flowers. The bees find flowers and begin to drink their liquid nectar. The nectar is stored in a special stomach, separate from where food is stored, called the honey stomach. Enzymes in this special stomach break down the nectar into sugars and water. *This broken down nectar and water is regurgitated into the honey cell of the hive.* The bees begin to move their muscles.
Manipulated event sentence (Consistent / Inconsistent version in bold):	The movement of the wing muscles **warms/cools** the surrounding air and the *honey cell*.
Target sentence:	The **heated** *water* inside of the cell evaporates.
End of chain:	The sugars inside the cell thicken, forming honey.

Part of text: Title:	How Hiccups Occur
Introduction/ start of chain (Prior knowledge sentence in italicized):	Virtually everyone experiences hiccups at some point, but they rarely last long or require a doctor's care. Hiccups occur because of a problem with the diaphragm, which is a dome-shaped muscle at the bottom of your chest. The diaphragm normally helps with breathing. *Specifically, the diaphragm pulls down to help suck air in while inhaling, and it relaxes to release air from the lungs when we exhale.* Hiccups begin when a person eats too quickly or feels nervous. These disturbances then irritate the nerves within the diaphragm. The nerves begin to fire irregularly.
Manipulated event sentence (Consistent / Inconsistent version in bold):	The diaphragm then rapidly ***pulls down/relaxes***.
Target sentence:	Some air is suddenly inhaled into the person's throat.
End of chain:	Lastly, the vocal chords close suddenly, producing the characteristic "hic" sound. Almost all cases of the hiccups last only a few minutes.

Part of text: Title:	How Supernovae Occur
Introduction/ start of chain (Prior knowledge sentence in italicized):	Stars are massive, glowing spheres of hot gases. *The star's layers include the iron core*. The iron core is located in the center of the star. The process of creating a supernova begins when the core runs out of hydrogen. The lack of hydrogen prevents further nuclear reactions within the star.
Manipulated event sentence (Consistent / Inconsistent version in bold):	The *star's layers* are **pulled inward/pushed outward**.
Target sentence:	The atoms of the *iron core* become **packed together**.
End of chain:	The iron atom nuclei repel away from one another, forcing the core to rebound outward. The rebound makes a huge shock wave. This violent shock causes the star to explode into a cloud of cosmic debris. The debris spreads out, creating a large cloud of gas known as a nebula.

Part of text: Title:	How a Delta Distributary Forms near a Sea
Introduction/ start of chain (Prior knowledge sentence in italicized):	As a river system meets a sea the river may split off into several smaller streams. The way in which the streams branch off from the river gives the area a look similar to a paper fan. That is, a single river (bottom of the fan) splits off into many water channels (the folds of the fan that radiate from the bottom). The region of smaller water channels is known as a delta distributary. *The formation of a distributary begins when the river current picks up and carries small rocks called sediment*. The river flows towards the outlet into the sea.
Manipulated event sentence (Consistent / Inconsistent version in bold):	Near the end of the river, the flow of the sea **reduces/increases** the speed of the *river's current*.
Target sentence:	The **slowing** *sediment* settles close to the river's end.
End of chain:	The deposited sediment builds up on the riverbed. Over time, the sediment blocks the river's connection to the sea. The river changes its course. As this process repeats, smaller channels from the river will develop and flow into the sea. This same process can occur near lakes and oceans.

Part of text: Title:	How Sediment Turns into Rock
Introduction/ start of chain (Prior knowledge sentence in italicized):	Sedimentary rocks develop from particles like pebbles and minerals, called sediments. Rock formation begins when wind, rain, or glacial movements deposit the sediments to a particular location. *As new layers are deposited, sediments build up with water in the areas between the particles.* Over time, new layers increase the pressure on the old layers.
Manipulated event sentence (Consistent / Inconsistent version in bold):	The space **shrinks/grows** between the sediment *particles* in the old layers.
Target sentence:	The *water* is **forced out** from in-between the particles.
End of chain:	Minerals are left behind between the larger sediment particles. The minerals fuse the sediments together and they harden. This results in the formation of sedimentary rocks.

Part of text: Title:	How the Northern Lights Form
Introduction/ start of chain (Prior knowledge sentence in italicized):	The Northern Lights is a multi-colored brilliant light show in the Earth's atmosphere. These lights are often seen in Alaska, Canada, and Norway. *The Northern Lights begin when the sun releases a solar storm composed of magnetically charged plasma into space.* Eventually, the solar storm hits the magnetic field above the Earth's atmosphere.
Manipulated event sentence (Consistent / Inconsistent version in bold):	The *solar storm* **combines with/rebounds from** the Earth's magnetic field.
Target sentence:	The *magnetically charged plasma* **flows towards** Earth's atmosphere.
End of chain:	The plasma streams towards the poles of the planet. The plasma collides with other particles in the atmosphere. These collisions emit different colored lights. The light show can last from 10 minutes to the entire night. The length of time depends on the size of the solar storm.

Part of text: Title:	How Frost Heaving Occurs
Introduction/ start of chain (Prior knowledge sentence in italicized):	The foundation of a house is a concrete block upon which the rest of the house is built. The foundation can take several different shapes. Frost heaving occurs to foundations that narrow at the bottom. Frost heaving can result in damage to the structure of the building or house. The process begins when a hole is dug into the ground. The dirt in the hole is firmly packed on all sides. The hole is filled with cement. *The cement completely fills the hole to eliminate gaps*. Later, during the winter months the topmost layers of ground freeze.
Manipulated event sentence (Consistent / Inconsistent version in bold):	The *foundation* **shifts upward/does not shift**.
Target sentence:	Loose sediment **falls in** the *gap* below the foundation.
End of chain:	When the weather warms in the spring, the top layers melt. The foundation sinks back down. However, the sediment below prevents the foundation from moving to its original position. The foundation may only move about a half an inch. Over time the change in position becomes much more apparent.

Part of text: Title:	How Muscles Grow
Introduction/ start of chain (Prior knowledge sentence in italicized):	Muscles are an incredibly important part of the body It would be impossible for you to do any action without your muscles. Each human muscle exists as long fibrous chains of tissue. The process of muscle growth begins when a particular muscle is exercised during a workout. Repeated use of the muscle creates micro tears on the muscles. The tears activate satellite cells around the muscles. *Satellite cells are special cells that transform into muscle*. The satellite cells fuse to the torn muscle.
Manipulated event sentence (Consistent / Inconsistent version in bold):	The *satellite cells* begin to **multiply/lessen**.
Target sentence:	A **large number** of *muscle cells* are made along the tear.
End of chain:	These extra muscle cells help create additional proteins for the muscle tissue. As a result, the muscles grow in size. As the muscle becomes adapted to exercise, soreness tends to decrease. The type of exercises and dietary needs to promote muscle growth and conditioning depend on the goals of the person.

Part of text: Title:	How a Poison Ivy Rash Forms
Introduction/ start of chain (Prior knowledge sentence in italicized):	The rash from poison ivy starts when a person's skin touches a poison oak, ivy or sumac plant. As a result of touching one of these plants, the plant oil is absorbed by the skin. Once absorbed, the oil is broken down into chemicals. *The chemicals bond with the cells in the skin*. The person’s immune cells recognize the oil as foreign to the body. The immune cells signal for white blood cells to travel to the location of the oil.
Manipulated event sentence (Consistent / Inconsistent version in bold):	This leads the white blood cells to **eat/ignore** the *chemicals*.
Target sentence:	The *skin cells* in the surrounding area are **attacked**.
End of chain:	The cells become extremely inflamed. A red rash develops on the skin. The rash appears 24 to 72 hours after exposure. The rash isn't contagious, so you won't spread it to others by going to school or work.

Part of text: Title:	How Geysers Erupt
Introduction/ start of chain (Prior knowledge sentence in italicized):	Geysers are among the rarest and most fragile natural phenomena on Earth. Geysers consist of a network of narrow cracks and fissures within the ground, known as a plumbing system. This plumbing system is located above a magma chamber. The process of a geyser erupting begins as groundwater enters into the plumbing system. *The additional water increases the pressure put upon water lower in the system.* While under high pressure, the magma chamber below superheats the water. The high pressure of the system prevents the superheated water from becoming steam. The superheated water reaches its boiling point.
Manipulated event sentence (Consistent / Inconsistent version in bold):	Some *water* **spouts from/flows into** the plumbing system.
Target sentence:	There is a **decrease** in *pressure* inside of the system.
End of chain:	The superheated water flashes into steam. The steam expands to 1,500 times the volume of water. The steam pushes a large amount of water out of the ground. These eruptions last as long as the water in the geyser remains hot enough to push water out of the geyser opening.

Part of text: Title:	How Arms and Legs "Fall Asleep"
Introduction/ start of chain (Prior knowledge sentence in italicized):	People describe the sensation of a limb falling asleep as a feeling like "pins and needles". This feeling has to do with the nerves in the limb. Arteries supply these nerves with nutrients. *These nutrients help the nerves regulate the transmission of signals sent to the brain*. The signals from the nerves communicate with the brain through the nerve pathways. The process of a limb falling asleep begins when pressure is applied to the body part.
Manipulated event sentence (Consistent / Inconsistent version in bold):	The nerves **no longer/continue to** get *nutrients* from the arteries.
Target sentence:	Then the *signals* being sent from the nerves are **disrupted**.
End of chain:	A few signals begin to travel towards the brain. The signals are held up by the pinched nerve pathway. Some of the signals arrive at the brain. The brain interprets the few signals as a tingling sensation. When pressure is removed, the body part "wakes up". This may lead to a feeling of increased tingling, followed by a more uncomfortable burning sensation before the body part finally returns to normal.

APPENDIX B

TASK INSTRUCTIONS AND TASK COMPREHENSION CHECKS

Read-for-Understanding Task

Reading Task

You will be reading several texts about different scientific processes. Each passage presents an explanation for a different scientific phenomenon (e.g., how lightning forms, how digestion works). Please read to understand each explanation for how each scientific process occurs.

Later on, you will be answering questions about the texts that you read.

Before you begin the task, we would like to make sure you understand the instructions. Below, please fill in the missing information from the instructions that you were given. If you can't recall the missing information, refer back to the prior instruction page.

Reading Task

You will be reading several texts about different scientific ________. Each passage presents an __________ for a different scientific __________ (e.g., how lightning forms, how digestion works). Please _______________ each explanation for ___ each scientific _____________.

Later on, you will be _________________ about the texts that you read.

Structure-and-Strategy Task

Reading Task

You will be reading several texts about different scientific processes. Each passage presents an explanation for a different scientific phenomenon (e.g., how lightning forms, how digestion works).

An explanation in science is a detailed series of causal statements that leads from an initial event to an outcome event. For instance, understanding how the sugar in soda (initial event) leads to obesity (outcome event) means learning about how physiological mechanisms such as ingesting sugar changes one's metabolic rate and hunger level, and how they relate to each other.

While you are reading, you should explain to yourself how the earlier events in the text cause each new event. To do so, you should check to make sure you understand what causes each event to bring about the next event. You should also regularly check that the connections between the events logically make sense.

Later on, you will be answering questions about the texts that you read.

Before you begin the task, we would like to make sure you understand the instructions. Below, please fill in the missing information from the instructions that you were given. If you can't recall the missing information, refer back to the prior instruction page.

Reading Task

You will be reading several texts about different scientific processes. Each passage presents an _______________ for a different scientific phenomenon (e.g., how lightning forms, how digestion works).

An explanation in science is a ______ series of ______ statements that leads from an ______ event to an _________ event. For instance, understanding how the sugar in soda (initial event) leads to obesity (outcome event) means learning about how physiological mechanisms such as ingesting sugar changes one's metabolic rate and hunger level, and how they relate to each other.

While you are reading, you should _______________ how the earlier events in the text cause each new event. To do so, you should check to make sure you understand what causes each event to bring about the next event. You should also ________________ that the connections between the events logically make sense.

Later on, you will be answering questions about the texts that you read.

Structure-only Task

Reading Task

You will be reading several texts about different scientific processes. Each passage presents an explanation for a different scientific phenomenon (e.g., how lightning forms, how digestion works).

An explanation in science is a detailed series of causal statements that leads from an initial event to an outcome event. For instance, understanding how the sugar in soda (initial event) leads to obesity (outcome event) means learning about how physiological mechanisms such as ingesting sugar changes one's metabolic rate and hunger level, and how they relate to each other.

Please read to understand each explanation for how each scientific process occurs. Later on, you will be answering questions about the texts that you read.

Before you begin the task, we would like to make sure you understand the instructions. Below, please fill in the missing information from the instructions that you were given. If you can't recall the missing information, refer back to the prior instruction page.

Reading Task

You will be reading several texts about different scientific processes. Each passage presents an _______________ for a different scientific phenomenon (e.g., how lightning forms, how digestion works).

An explanation in science is a ______ series of ______ statements that leads from an ______ event to an _________ event. For instance, understanding how the sugar in soda (initial event) leads to obesity (outcome event) means learning about how physiological mechanisms such as ingesting sugar changes one's metabolic rate and hunger level, and how they relate to each other.

Please read to understand each explanation for ____ each scientific process __________. Later on, you will be answering questions about the texts that you read.

APPENDIX C

CONFLICT DETECTION INSTRUCTIONS AND QUESTIONS

Instructions

For the next part of the experiment, please begin by considering the following excerpt from a text about how lightning forms:

> Droplets of water collide with other moisture within the cloud.
> Negatively-charged electrons are knocked off of the moisture.
> Rising water droplets pull the released electrons upward.
> The top of the cloud becomes positively charged.

Below is one of the sentences you just read. Please rate how inconsistent any part of the sentence was with any information from the text by circling one of the numbers below:

> The top of the cloud becomes positively charged.

Consistent 1 --- 2 --- 3 --- 4 --- 5 --- 6 Inconsistent

The sentence you just rated is actually <u>inconsistent</u> with the other details of the excerpt. The conflict arises because the earlier sentence describes the electrons as being negatively charged, and the following sentence says that the electrons are pulled upward. This would make the top of the cloud negatively charged, which conflicts with the next sentence that the top of the cloud becomes positively charged.

The texts that you read earlier may or may not have been inconsistent. We would like to see if you remember any conflicts being present. On the next screen, you will be shown a sentence from the text, just as in the example above. You should rate how inconsistent any part of the sentence was with any part of the text that you read. You can choose your rating by pressing the number keys 1 through 6 on the keyboard.

As soon as you press a number, the next sentence on another topic will immediately appea

Rate how inconsistent any part of this sentence is with any of the information from each text you read:

Sweat:
The glands release a large amount of sweat onto the skin.

Consistent 1--2--3--4--5--6 Inconsistent

Honey:
The heated water inside of the cell evaporates.

Consistent 1--2--3--4--5--6 Inconsistent

Hiccups:
Some air is suddenly inhaled into the person's throat.

Consistent 1--2--3--4--5--6 Inconsistent

Supernovae:
The atoms of the iron core become packed together.

Consistent 1--2--3--4--5--6 Inconsistent

Delta Distributaries:
The slowing sediment settles close to the river's end.

Consistent 1--2--3--4--5--6 Inconsistent

Geysers:
There is a decrease in pressure inside of the system.

Consistent 1--2--3--4--5--6 Inconsistent

Sedimentary Rocks:
The water is forced out from in-between the particles.

Consistent 1--2--3--4--5--6 Inconsistent

Frost Heaving:
Loose sediment falls in the gap below the foundation.

Consistent 1--2--3--4--5--6 Inconsistent

The Northern Lights:
The magnetically charged plasma flows towards Earth's atmosphere.

Consistent 1--2--3--4--5--6 Inconsistent

Arms and Legs Falling Asleep:
Then the signals being sent from the nerves are disrupted.

Consistent 1--2--3--4--5--6 Inconsistent

Muscle Growth:
A large number of muscle cells are made along the tear.

Consistent 1--2--3--4--5--6 Inconsistent

Poison Ivy:
The skin cells in the surrounding area are attacked.

Consistent 1--2--3--4--5--6 Inconsistent

APPENDIX D

SCIENTIFIC EXPLANATION QUESTION

Please write 3-5 sentences answering the following question:

Scientists often present explanations that describe how scientific phenomenon occur (e.g., how lightning forms, how digestion works). When reading these types of explanations, what do you think is important to pay attention to in order to best understand the phenomenon?

APPENDIX E

FINAL SURVEY

Academic History and Demographic Information

HIGH SCHOOL
Mark all of the courses listed below that you took *during high school*.

- □ Astronomy
- □ Biology
- □ Chemistry
- □ Economics
- □ Logic
- □ Physics
- □ Political science
- □ Psychology
- □ Sociology
- □ Statistics

Did you take part in a science fair during high school (circle one)? YES NO

COLLEGE
Mark all of the courses listed below that you have taken *during college* (including this semester).

- □ Astronomy
- □ Biology
- □ Chemistry
- □ Economics
- □ Logic
- □ Journalism
- □ Physics
- □ Political science
- □ Psychology
- □ Research methods (science)
- □ Sociology
- □ Statistics

Have you taken any 300-400 level psychology courses? YES NO
If so, how many, including any you are currently taking? ________

What is your gender (circle one)? MALE FEMALE
What is your age? _____________
What is your year in school? Freshman Sophomore Junior Senior

Please mark how you identify yourself in terms of ethnicity and/or race. Feel free to mark more than one category.

_____ Hispanic/Latino
_____ Asian
_____ Native Hawaiian or Pacific Islander
_____ Other: Specify ____________________
_____ American Indian or Alaska Native
_____ Black or African American
_____ White

APPENDIX F

TABLE 11

Means and Standard Deviations for Target Reading Times across Text Consistency and Task for participants with and without ACT scores, in msec/syl.

	Consistent	Inconsistent
Read-to-Understand	294.08 (208.49)	305.42 (196.87)
Structure-only	270.67 (151.32)	299.58 (200.57)
Structure-and-Strategy	260.82 (153.71)	264.50 (139.14)

APPENDIX G

TABLE 12

Means and Standard Errors for Target Reading Times across Text Consistency and Task, 1 standard deviation above and below the mean of ACT science score, in msec/syl.

	Read-to-Understand		Structure-only		Structure-and-Strategy	
	Consistent	Inconsistent	Consistent	Inconsistent	Consistent	Inconsistent
Less-skilled (1 SD below mean)	266.36 (27.66)	265.57 (29.78)	272.86 (23.96)	313.55 (29.00)	275.56 (23.16)	286.02 (22.29)
More-skilled (1 SD above mean)	261.10 (23.12)	282.28 (24.46)	298.96 (28.01)	307.63 (34.57)	251.09 (23.74)	258.83 (22.95)