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# Cognitive Processes in Comprehension of Science Texts: The Role of Co-Activation in Confronting Misconceptions

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SUMMARY

In this paper, we investigate the effects of readers' incorrect knowledge on the on-line comprehension processes during reading of science texts, with an eye towards examining the conditions that encourage revision of such knowledge. We employed computational (Landscape Model) and empirical (think-aloud and reading times) methods to compare comprehension processes by readers with correct and incorrect background knowledge, respectively. Science texts were presented in either regular or refutation versions; Prior research using off-line methods suggests that refutation versions promote revision in readers with incorrect knowledge. The results of the current study indicate that incorrect knowledge systematically influences both type and content of processing. Moreover, simultaneous activation of correct and incorrect conceptions during reading plays an essential role in knowledge revision: The computational simulations show that refutation texts create optimal circumstances for co-activation of the incorrect and correct conceptions and the empirical data show that such a co-activation is associated with inconsistency detection and revision activities by the readers with incorrect knowledge. These findings provide insights in the effects of misconceptions on the on-line text processing and have important implications for the development of methods for achieving revision during reading. Copyright © 2008 John Wiley & Sons, Ltd.

Much of the learning that takes place in and out of schools is based on successful comprehension of texts. During comprehension readers construct a memory representation of the text that critically depends on their interpretation in light of prior knowledge. The success of the comprehension process, therefore, is contingent on the integration of readers' prior knowledge with textual information (Goldman & Bisanz, 2002; Kintsch, 1988, 1998; van den Broek, Virtue, Gaddy, Tzeng, & Sung, 2002). The powerful effects of readers' prior knowledge in text comprehension were documented as early as the beginning of the 20th century (Bartlett, 1932). Since then, considerable evidence has been accumulated that shows that both young and adult readers who have prior knowledge related to the content of a text have much better memory of the text than readers who do not have that knowledge (e.g. Chiesi, Spilich, & Voss, 1979; Dochy, Segers, & Buehl, 1999; Means & Voss, 1985; Recht & Leslie, 1988). Much less attention has been paid, however, to the role of *inaccuracy* of prior knowledge, despite the fact that readers with inaccurate knowledge—misconceptions—are the default case rather than the exception (Driver,

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Squires, Rushworth, & Wood-Robinson, 1994; Kendeou, Rapp, & van den Broek, 2003; Perkins & Simmons, 1988). Problems resulting from misconceptions occur for all types of text, but they are particularly evident in students' learning from science texts. All too often inaccurate prior knowledge interferes with the development of accurate mental models of scientific principles and of correct explanations of what is happening in the physical world (Carey, 1985). These models and explanations may rely on naïve rather than scientifically informed beliefs, resulting in inaccurate knowledge structures (Nussbaum & Novak, 1976; Sneider & Poulos, 1983; Vosniadou & Brewer, 1992, 1994).

In this paper, we consider the effects of misconceptions on the on-line comprehension process during reading of science texts, with an eye towards developing ways to encourage revision of these inaccurate ideas. In particular, we describe the essential role that simultaneous activation of correct and incorrect conceptions plays in such revision. We do so through a combination of computational and empirical methods based on cognitive theories of the reading process.

## MISCONCEPTIONS IN SCIENCE LEARNING

As mentioned, inaccurate prior knowledge is the norm rather than the exception for students. Misconceptions usually (though not always) are intuitive and are formed in an attempt to understand everyday life experiences (Hewson & Hewson, 1984). They concern many phenomena in science (e.g. earth science, electrical circuits, energy, etc.) and appear in all age groups (Linn, 1986, as cited in Reference Pace, Marshall, Horowitz, Lipson, & Lucido, 1989). Misconceptions are extraordinarily resistant to change because they are often perfectly reasonable to those who hold them and because people often are committed to them, given that they are developed through personal effort to understand and explain the world (Guzzetti, Snyder, Glass, & Gamas, 1993; Pace et al., 1989). Moreover, misconceptions often are embedded in well-organized conceptual systems (Carey, 1985).

Importantly, misconceptions interfere with the learning of new, related information (Diakidoy, 1999; Feltovich, Coulson, & Spiro, 2001; Guzzetti, 1990, 2000; West & Pines, 1985) and thus pose a significant educational risk. For this reason, educational psychologists have started to theorize on the complex cognitive processes involved in the modification of misconceptions, which is called *conceptual change* (Hynd & Guzzetti, 1998; McCloskey, 1982; Vosniadou, 2003), and to explore effective ways of accomplishing conceptual change. With regard to theory, this has led, for example, to the Conceptual Change Model (CCM) (Posner, Strike, Hewson, & Gertzog, 1982) that posits that four conditions need to be met for conceptual change to occur: (1) the student must feel dissatisfaction with an existing conceptualization, (2) an intelligible new concept must be available, (3) the plausibility of the new concept or idea must be demonstrated and (4) the student must see this new conception as both useful and appropriate.

With regard to practical ways for achieving conceptual change, focus has been on changing the structure of texts. Prior research has shown that textbook writing often is lacking in clarity about central ideas and concepts (Goldman & Bisanz, 2002) and fails to be informed by theories of text processing (Beck, McKeown, Sinatra, & Loxterman, 1991). Methods for improving the clarity, for example by enhancing coherence and by making implicit connections between text elements explicit (Britton & Gulgoz, 1991), lead to better memory of the textual information (Britton, Van Dusen, Gulgoz, & Glynn, 1989), particularly for low-skill readers (Linderholm, Gaddy, van den Broek, Mischinski, & Crittenden, 2000).



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Although this research concerns teaching students new conceptions rather than correcting erroneous prior beliefs, it has prompted investigators to consider text structure as a route to overcome misconceptions as well. Indeed, one specific type of science text has repeatedly been found effective in changing misconceptions: refutation texts. *Refutation texts* aim to persuade students to change prior beliefs by explicitly detailing misconceptions and explaining the correct ideas (Guzzetti et al., 1993). Presenting information in such format has been found to alter students' misconceptions in elementary, secondary and college level structure (Alvermann & Hague, 1989; Alvermann & Hynd, 1989; Anderson & Smith, 1986; Diakidoy & Kendeou, 2001; Diakidoy, Kendeou, & Ioannides, 2003; Guzzetti, Williams, Skeels, & Wu, 1997; Hynd & Alvermann, 1986; Lipson, 1982; Maria, 1988, as cited in Reference Guzzetti et al., 1993; Maria & Johnson, 1989; Maria & MacGinitie, 1987).

Although the use of a refutation structure tends to be conducive of conceptual change, it is not clear why this text structure is more effective than others—or, under what circumstances it is. Consistent with Posner's CCM (Posner et al., 1982), researchers have speculated that refutation texts are effective because they create cognitive conflict (Guzzetti et al., 1993), provide coherent and credible explanations (Hynd, McNish, Qian, Keith, & Lay, 1994), or both (Guzzetti et al., 1997).

Understanding the mechanism by which refutation texts exert their influence is important for several reasons. First, it allows us to determine exactly what requirements a successful refutation text needs to meet and thus to optimize the structure of these texts. Second, by providing us insight into how conceptual change is accomplished in this particular manner, it may suggest guiding principles for the development of methods for achieving conceptual change other than through text structure. Third, it would foster the development of a theory of the nature of the cognitive structures and processes that are involved in misconceptions and their interaction with incoming new information.

In the following sections we explore the cognitive processes that may form the foundation for the success of refutation texts. We focus on an important component of the processing invoked by refutation texts—co-activation—that is not included in the various accounts of its success and argue that this component is indeed required before steps such as those detailed in the CCM can take place. Co-activation thus is likely to provide the basis for conceptual change and, hence, is essential for methods designed to promote such change.

In doing so, we focus on the *on-line* processing. Although most researchers *assume* that the reasons refutation texts are effective somehow involve the processing that takes place during the act of reading itself, in reality little is known about the on-line processing of readers with and without misconceptions. This is because the vast majority of studies use *off-line* assessments, after the actual reading process has been completed. To understand why and how refutation texts exert their effects, it is essential to gain a thorough understanding of the on-line processes by which readers with and without misconceptions understand refutation and non-refutation scientific texts. In the current research, we address the limitations of the current knowledge base by focusing on this on-line processing during comprehension.

## COGNITIVE PROCESSES IN READING REFUTATION TEXTS

To better understand how readers' cognitive processing affects readers' learning from scientific texts, we follow a three-step approach (cf. Magliano & Graesser, 1991; van den Broek, Fletcher, & Risden, 1993). First, we form hypotheses with respect to readers'

 
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processing of scientific texts drawing on recent research in cognitive psychology and discourse processing. In particular, we use the conceptual framework of the Landscape model, in which many of the comprehension processes identified in cognitive research are integrated. Second, we perform simulations to test our hypotheses using the computational implementation of the Landscape Model (Tzeng, van den Broek, Kendeou, & Lee, 2005). Third, we collect empirical data on the reading process to compare with the computational data.

## The framework of the landscape model

The Landscape model was developed to capture the comprehension processes that take place during reading and their relation to the gradually emerging memory representation of a text (van den Broek, Risden, Fletcher, & Thurlow, 1996; van den Broek, Young, Tzeng, & Linderholm, 1999; available at http://www.education.umn.edu/edpsych/projects/landscapemodel/default.html). The model integrates findings of numerous studies by many researchers in a single theoretical framework. In the Landscape model, the processes that take place at each point during reading reflect a balancing of the reader's limited attentional resources with the standard of coherence and comprehension that the reader—implicitly or explicitly—sets (van den Broek, Rapp, & Kendeou, 2005). As a result, as the reader proceeds through the text, concepts (propositions, informational units) fluctuate in activation: With each new cycle (e.g. sentence) some concepts continue to be active, others decline in activation and yet others become newly (re)activated. The fluctuations in activation occur as a function of four sources of information: the text input in the current processing cycle, residual information from the preceding cycle, the episodic memory representation of the text read so far, and reader's background knowledge including possible misconceptions.

Two types of mechanisms guide access to the latter two sources of activation, the memory representation for the text and semantic knowledge. The first type is *cohort activation*: when one concept is activated during reading, all other concepts that are—or, over the course of reading, have become—associated with it are activated as well. Cohort-activation is passive, automatic and not under the reader's control. Thus, it is memory based and similar to the spread-of-activation mechanisms described by the Resonance Model (McKoon, Gerrig, & Greene, 1996; Myers, & O'Brien, 1998; O'Brien & Myers, 1999; O'Brien, Rizella, Albrecht, & Halleran, 1998; van den Broek et al., 2005) and the Construction-Integration model (Kintsch, 1988, 1998).

The second type of mechanism is *coherence-based retrieval.* Coherence-based retrieval is a strategic mechanism by which information is retrieved with the aim of meeting a reader's standards or goals (Linderholm, Virtue, Tzeng, & van den Broek, 2004; van den Broek et al., 2005). Such retrieval can be from the episodic text representation constructed so far, from prior knowledge, or from the text itself (e.g. via look-backs in a text). This mechanism operates under a limited pool of activation and is strategic. Thus, coherence-based retrieval is similar to 'search/effort after meaning' mechanisms described by the constructionist view of reading (Graesser, Singer, & Trabasso, 1994; Singer, Graesser, & Trabasso, 1994).

Whether coherence-based processes are invoked or whether cohort activation is adequate depends on the *standards of coherence* that the reader maintains during reading (van den Broek, Risden, & Husebye-Hartmann, 1995). In each particular reading situation, a reader employs standards about what constitutes adequate comprehension. These



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standards of coherence vary in type (e.g. referential, causal, temporal and spatial coherence) as well degrees of strictness as a function of individual differences (e.g. motivation), text types, reading goals and so on (Linderholm & van den Broek, 2002; Narvaez, van den Broek, & Ruiz, 1999; van den Broek, Tzeng, Virtue, Linderholm, & Young, 2001). At each reading cycle, if the reader's standards are met by the information currently activated through cohort activation then there is no need for strategic processes such as coherence-based retrieval. If, however, the cohort-activated information does not meet the standards the reader may need to actively search the episodic text representation and/or prior knowledge through coherence-based retrieval to maintain these standards. In this fashion, a reader's standards of coherence modulate when strategic processes are and are not invoked (Calvo, Castillo, & Schmalhofer, 2006; van den Broek et al., 2005).

In the Landscape model, the patterns of concept activations at each cycle are central for comprehension because they form the basis for the construction of a memory representation of the text and related knowledge as an integrated whole. For each reading cycle, the particular concepts that are activated are added as nodes to the developing episodic memory representation of the text. If a concept is already part of the text representation and is reactivated, its trace is strengthened. In addition, when concepts are co-activated in a cycle a connection between these concepts is established (or strengthened, if a connection already existed). Connected concepts form a cohort which, as discussed above, provides the basis for cohort-activation. Thus, on the one hand, the cyclical and dynamically fluctuating activations lead to the gradual emergence of an episodic memory representation of the text, in which textual units and inferences are connected via semantic relations; On the other hand, at each cycle the network representation constructed during the preceding cycles influences subsequent activation patterns through cohort-activation. Thus, the Landscape model captures the fluctuations of concepts during reading, the evolving text representation in memory, as well as the reciprocal and dynamic interaction between on-line fluctuations and off-line representation.

## Landscape model simulations

By providing a description of the processes by which background knowledge is connected with textual information, the Landscape model provides insights in conceptual change of misconceptions. Importantly, in the model it is only information that is co-activated that can be compared, integrated and so on. This suggests that an essential prerequisite for conceptual change is that the reader with the misconception activates the incorrect concepts at the same time as the correct ones. It is only after such co-activation occurs that further steps in conceptual change such as cognitive conflict (Guzzetti et al., 1993) and dissatisfaction with one's current conceptualization (Posner et al., 1982) can take place. The window of opportunity for such co-activation is brief: concepts activated in one cycle will not be activated anymore even only a few cycles later unless they are (re)activated, for example through the cohort-activation and coherence-based processes described above. To determine whether a particular reading context or instructional manipulation achieves the necessary co-activation one needs to consider the detailed on-line processes and the way in which these create the constantly fluctuating activation patterns from one reading cycle to the next. With respect to refutation texts, we propose that their particular effectiveness originates from the fact that in refutation texts the correct and incorrect conceptualizations are presented in close proximity and, therefore, with very high likelihood of simultaneous activation.



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To illustrate how one can keep track of the various processes involved in the activation of concepts—and in co-activation of misconceptions and correct knowledge in particular—and how refutation texts may derive their effectiveness from promoting co-activation, we turn to the computational implementation of the Landscape Model. The complexity of on-line processes and on-line representations makes a computational approach a very useful tool to consider the simultaneous impact of the multiple components within a model and examine their interactions (Goldman, Golden, & van den Broek, 2007).

In the following simulations we investigate the availability of information critical to comprehension during reading of refutation and non-refutation scientific texts. Two texts were used, each describing a common problem in Newtonian Mechanics. The texts were adapted from McCloskey (1982). The following is the refutation version of one of the texts:

> Newtonian mechanics explains many phenomena related to your everyday life. Imagine the following situation. A person is holding a stone at shoulder height while walking forward at a brisk pace. What will happen when the person drops the stone? What kind of path will the stone follow when it falls? Many people to whom this problem is presented answer that the stone will fall straight down, striking the ground directly under the point where it was dropped. A few people are even convinced that the falling stone will land behind the point of its release. In reality, the stone will move forward as it falls, landing a few feet ahead of the release point. Newtonian mechanics explains this phenomenon: When a stone is dropped, it continues to move forward at the same speed as the walking person, because no force is acting to change its horizontal velocity.

Note that in addition to presenting the correct scientific idea, that *When a stone is dropped, it continues to move forward at the same speed as the walking person, because no force is acting to change its horizontal velocity*, the refutation text also acknowledges two common misconceptions, first that *the stone will fall straight down, striking the ground directly under the point where it was dropped* and second, *that the falling stone will land behind the point of its release*. Both misconceptions have been documented in the science education literature as frequent among students (Hestenes & Halloun, 1995; Hestenes, Wells, & Swackhamer, 1992). This is a typical refutation text structure. In contrast to the refutation version of the text, the non-refutation version simply presents the correct scientific conception without any reference to common misconceptions.

We parsed the refutation and non-refutation versions of both texts into idea units (41 ideas units in each text) and identified the different sources of activation for each idea unit in every reading cycle (see Reference Linderholm et al., 2004 for details on the parsing and connecting). In doing so, we used two standards of coherence, referential and causal, which in prior research have been found to be adopted routinely by most readers in most reading situations and to be central for adequate comprehension. Idea units that were explicitly mentioned received the highest activation (5 on a 5-point scale). Idea units activated as a result of readers' referential or causal standards of coherence received slightly less activation (4 on a 5-point scale). Idea units activated to establish causally enabling relations received even less activation (3 on a 5-point scale). Each sentence constituted a reading cycle, yielding a total of 10 reading cycles.

The main goal of the simulations was to investigate the availability of correct and incorrect idea units for the refutation and the non-refutation text versions, respectively. We focused on the activation patterns at the sentence introducing the correct scientific idea for the sample text: *when a stone is dropped, it continues to move forward at the same speed as*



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*the walking person, because no force is acting to change its horizontal velocity* (sentence 10 in the text). This sentence is present in both text versions and thus, the correct information is expected to be available (i.e. activated) in both versions. The issue of main interest concerns the availability of the idea units that represent misconceptions when a hypothetical reader processes this sentence in the refutation and non-refutation versions, respectively.

Figure 1 shows the activation of the critical idea units in the text (i.e. the stone falling straight down, the stone falling behind, and the stone falling forward), during reading of the target sentence 10 in the refutation text. Figure 2 shows the same information for the non-refutation text.

As can be seen, when a hypothetical reader reads that *when a stone is dropped, it continues to move forward at the same speed as the walking person, because no force is acting to change its horizontal velocity* in the refutation text (Figure 1), all three idea units, namely the incorrect notions that the stone will fall straight down (activation value = 3.56) and that the stone will fall behind (activation value = 2.98) and the correct notion that the stone will move forward (activation value = 3.75), are highly activated.

In contrast, when a hypothetical reader reads that *when a stone is dropped, it continues to move forward at the same speed as the walking person, because no force is acting to change its horizontal velocity* in the non-refutation text (Figure 2), the incorrect notions that the stone will fall straight down (activation value = 1.49) and that the stone will fall behind (activation value = .76) are not very strongly activated, with activations of 1.49 and .76, respectively. Only the correct scientific idea that the stone will move forward is highly activated (activation value = 5.00). Thus, during reading of this version of the texts the correct conceptualization is activated in isolation of the misconceptions.

The results of these simulations indicate that during reading of a refutation text, correct and incorrect ideas are co-activated by the reader. No such co-activation is observed during reading of a traditional, non-refutation text. This suggests that refutation texts increase the likelihood of readers experiencing conceptual change by creating a precondition essential for detecting the contradiction between correct and incorrect ideas during reading. Put succinctly, the detection of a potential contradiction described in models of conceptual change (Guzzetti et al., 1993; Posner et al., 1982) is made possible by the co-activation of the contradictory pieces of information.

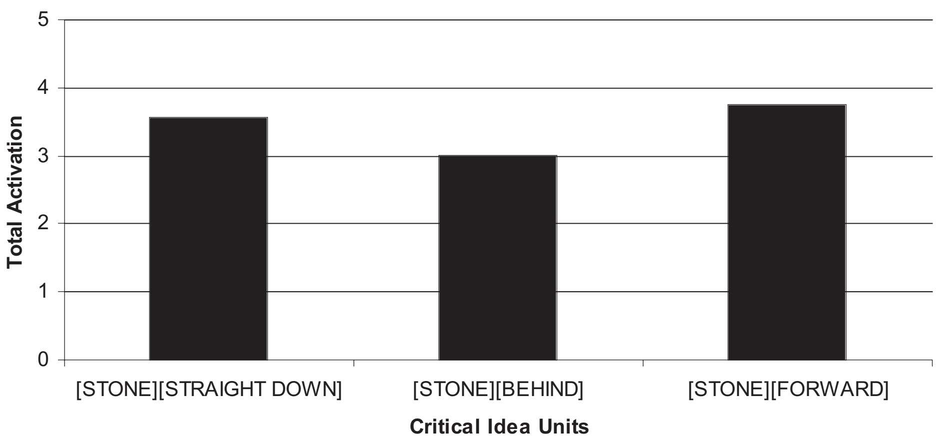


Figure 1. Activation of critical information in reading cycle 10 in the refutation text



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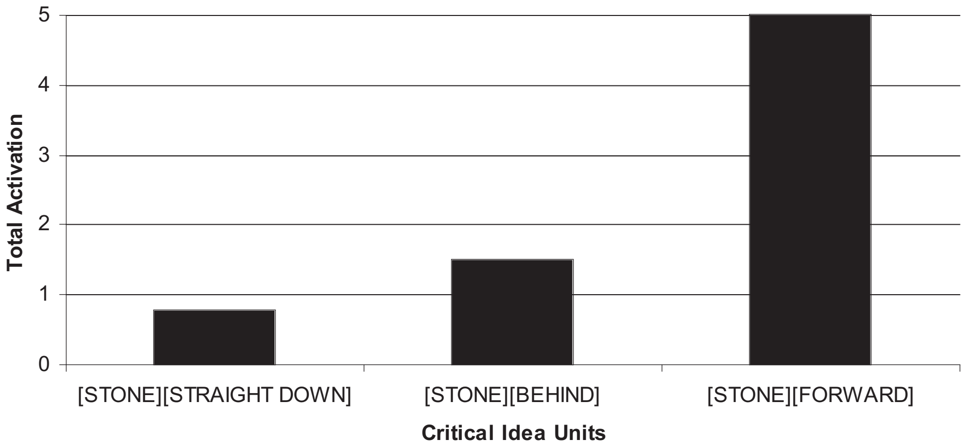


Figure 2. Activation of critical information in reading cycle 10 in the non-refutation text

## Empirical evidence

The description of cognitive processes during reading comprehension and the simulations outlined above suggest that refutation texts may be effective because they create optimal circumstances for co-activation of the misconceptions and correct conceptualizations and, thereby, provide the foundation for further processing that differs fundamentally from the processing that takes place during reading of traditional, non-refutation texts. To determine whether such differences in processing indeed occur, we conducted two empirical experiments on the on-line processing of refutation and non-refutation science texts by readers with and without misconceptions related to the topics of the text (for details, see Kendeou & van den Broek, 2007). In Experiment 1, a think-aloud methodology was employed because it allows the consideration of a variety of reader responses (Ericsson & Simon, 1993; Pressley & Afflerbach, 1995; Trabasso & Suh, 1993). This methodology has been found to be very useful as a tool to reveal comprehension processes in reading (Afflerbach, 2002; Coté & Goldman, 1999; Magliano & Graesser, 1991; Magliano & Millis, 2003; Zwaan & Brown, 1996). In Experiment 2, a reading time methodology was employed because it is unobtrusive and is sensitive to both conscious and subconscious processes (Lorch & van den Broek, 1997; Rapp, Gerrig, & Prentice, 2001; Rayner, Chace, Slattery, & Ashby, 2006).

In Experiment 1, readers read the same texts as were used in the simulations, while performing a think-aloud task. The readers had been identified as either high or low (both $N$s $= 40$) in terms of misconceptions about the topics of the text through the Force Concept Inventory, a test designed specifically to assess common misconceptions of Newtonian principles (Hestenes & Halloun, 1995). The responses during the think-aloud procedure were coded for the different cognitive processes in which readers engage during reading. These processes included *monitoring comprehension* (responses that show readers' awareness of their comprehension, problems they encountered, and whether they understood or failed to understand), *conceptual change strategies* (responses that show that readers engage in conceptual change, such as experiencing cognitive conflict, responding to conflict and contrasting information), *using prior knowledge* (responses that show that readers activate, access and integrate the text material with prior knowledge), *paraphrases,*



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*text repetitions*, *correct inferences* (correct explanatory, predictive and other inferences) and *incorrect inferences* (incorrect explanatory, predictive, and other inferences).

Analysis of the think-aloud responses revealed both similarities and dissimilarities in the processes of readers with misconceptions and those of readers without misconceptions. With regards to similarities, the degree to which readers monitored their comprehension, used prior knowledge, and interconnected sentences in the text was unaffected by the accuracy of their prior knowledge or by text structure (all *p*s $> .05$). Readers' processing differed, however, as a function of accuracy of prior knowledge and text structure with respect to engaging in conceptual change strategies and generating correct and incorrect inferences. Particularly, readers with misconceptions engaged in conceptual change strategies more often than did readers without misconceptions, but *only* during reading of refutation text and not during reading of non-refutation text (Figure 3). There was no difference in the frequency of conceptual change processes for refutation and non-refutation texts by readers without misconceptions, nor was there a difference between readers with and those without misconceptions when reading the non-refutation text.

In addition, for both refutation and non-refutation texts readers with misconceptions generated more incorrect (difference in average number of inferences per text $= 3.8$, $p < .001$) and fewer correct (difference $= 6.4$, $p < .001$) inferences that did readers without misconceptions. These inferences included, among others, attempts to explain information in the text (explanatory inferences) and attempts to make predictions (forward inferences).

In Experiment 2, readers with and without misconceptions (both $N$s $= 30$) read the refutation text or the non-refutation text on the computer, one sentence at a time in a self-paced manner. They then recalled the text. Analysis of the reading times for the sentences with the correct information (which conflicted with the prior knowledge of readers with misconceptions) showed that readers with misconceptions spent more time reading those sentences than did readers with no misconceptions but only when these sentences were included in a refutation text (difference $= 104$ ms, $p < .05$). For the refutation text the reading times of target sentences by readers with and without misconceptions did not differ (difference $= 30$ ms, $p > .05$).

These results indicate that texts that promote co-activation of misconception and correct information (refutation text) elicit fundamentally different comprehension processes in

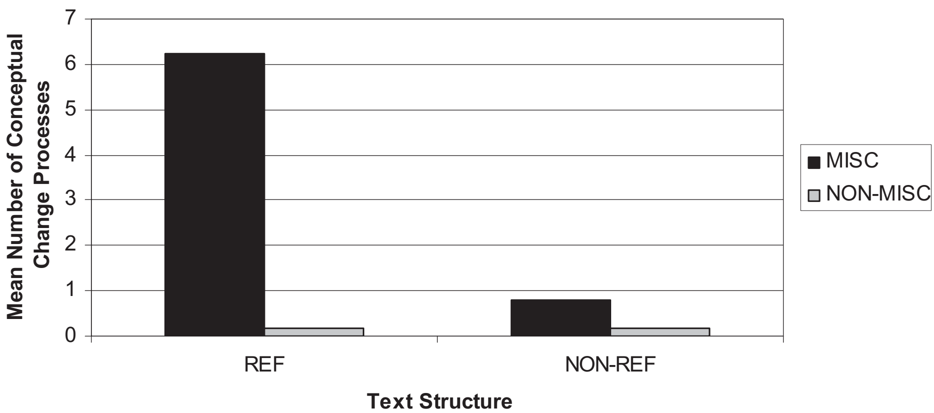


Figure 3. Mean number of conceptual change processes by readers with (MISC) and without (NON-MISC) misconceptions in refutation (REF) and non-refutation (NON-REF) text



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readers with misconceptions than do texts that do not promote co-activation (non-refutation text). When reading the refutation texts, readers with misconceptions read the sentences with correct information more slowly (Exp. 2) and engaged in more conceptual change behaviours (Exp. 1) than when reading the non-refutation texts. Thus, the co-activation of misconceptions and correct information led readers with misconceptions to experience conflict (i.e. they detected the inconsistency between their prior knowledge and the textual information) and allowed them to engage in efforts to repair the conflict and create coherence. In contrast, readers with misconceptions who read the text version that did not promote co-activation did not slow down or engage in conceptual change behaviours anymore than did readers without misconceptions. Further, as expected, all readers with misconceptions generated fewer correct and more incorrect inferences than did readers without misconceptions. Finally, the readers without misconceptions were not influenced in their processing by the type of text they read.

## DISCUSSION

Consideration of the cognitive processes that take place during reading provides an explanation for the well-documented success of refutation texts in bringing about conceptual change in readers with misconceptions. In particular, refutation texts increase the likelihood that readers co-activate incorrect prior knowledge and correct scientific conceptions depicted in the text and, in doing so, help them detect the inconsistency between their prior knowledge and the text. Current cognitive theories of reading comprehension—as exemplified by the Landscape model—point to the importance of co-activation of to-be-connected or to-be-compared information for allowing integration or, in the case of misconceptions, conceptual change. Indeed, our simulations of the reading of refutation and non-refutation texts reveal that refutation texts create optimal circumstances for co-activation of the misconceptions and correct conceptualizations and the empirical think-aloud and reading-time data show that such co-activation is associated with inconsistency detection and conceptual change activities by readers with misconceptions.

The conclusion, based on investigation of on-line comprehension processes, that co-activation is a crucial step in the detection and possible resolution of conflicts between one's prior, incorrect knowledge and new, correct knowledge is consistent with prior speculations that the reason for the success of refutation texts may be that readers with misconceptions become aware of conflicts between their knowledge and the correct information when reading a refutation text (e.g. Chinn & Brewer, 1993; Guzzetti et al., 1993; Hewson & Hewson, 1984; Hynd et al., 1994; Kendeou et al., 2003). Such speculations were prompted by the observation that students have better performance in off-line tasks such as free-recall, application-question and problem-solving tasks after reading a refutation text than after reading a traditional science text. The results of the present study show the actual reading processes themselves, as they unfold during reading of the text, and provide evidence that during reading of refutation text readers co-activate and integrate prior knowledge and text information which, in turn, allows them to detect the inconsistency between their knowledge and the text. In doing so, the current findings complement and extend the findings and speculations from prior off-line research.

Co-activation of misconceptions and correct information, then, is a necessary step toward conceptual change. By allowing the detection of inconsistencies, co-activation enables readers to engage in additional processing in an attempt to establish coherence



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(Glenberg, Wilkinson, & Epstein, 1983; Graesser et al., 1994; McNamara & Kintsch, 1996) or reconcile the inconsistent information (e.g. Hakala & O'Brien, 1995; Linderholm et al., 2004). It is important to note, however, that experiencing conflict or detecting the contradiction may be necessary but it is not sufficient for successful conceptual change to take place (Kendeou & van den Broek, 2005). Rather, it is an essential first step (cf., Chinn & Brewer, 1993; Dole & Sinatra, 1998; Posner et al., 1982). Other factors determine whether conceptual change will successfully take place. These factors include the degree to which the reader experiences violation of his/her standards of coherence (van den Broek et al., 1995) or dissatisfaction and conflict, the plausibility of the new scientific information (Posner et al.), and the strength of the existing concept and readers' commitment to it (Dole, 2000).

The above processes are described here in the context of scientific texts but, given the right circumstances, they also occur in the reading of other texts types. Inconsistencies between textual information and the reader's background knowledge can occur during reading of reading other expository types of texts, of narratives, but also of non-standard texts such as webpages, recipe books, instructions for assembling items and so on. Anytime there is a contradiction between knowledge and text, co-activation and subsequent contradiction-repairing processes may take place. The factors indicated at the end of the previous paragraph modulate the likelihood of conceptual change in these situations as well. For example, standards for coherence may be relaxed for certain types of text—for instance, fiction—resulting in the reader passing over a contradiction that would have been noticed in another (textual) context. Similarly, the above account can be extended to non-textual situations in which prior knowledge conflicts with new information. An example concerns situations in which a person holds biases or prejudices against a population and fails to update such beliefs in light of direct experiences with people who are counterexamples to these biases and prejudices. The above account could be adapted easily to capture conceptual change processes (or the failure to engage in such processes) in these situations as well. Here too, if one aims to dispel a person's erroneous beliefs it is important to co-activate the prejudice/bias and the counterexperience (for example, by stating the bias explicitly when presenting counterexperiences).

Returning to texts, it should be noted that the processes involved in recognition and resolution of contradictions between textual information and semantic knowledge are analogous to those described for the processing of contradictions that occur *within* texts. In the latter circumstances, cohort activation and coherence-based processes, modulated by standards of coherence, also have been found to determine the likelihood of inconsistency detection (O'Brien et al., 1998; Rapp & Kendeou, 2007; Schmalhofer, Friese, Pietruska, Raabe, & Rutschmann, 2005; van den Broek et al., 2005; Yang, Perfetti, & Schmalhofer, 2007).

## THEORETICAL AND PRACTICAL IMPLICATIONS

The findings of the present investigation have important theoretical and practical implications. From a theoretical perspective they provide insight in the impact that misconceptions can have on the process of comprehension as a reader proceeds through a text. Unless the misconception is activated simultaneously with the correct information, the two are likely to not conflict in the reader's perception. If they do not conflict then no conceptual change or correction of the misconception will take place. The new, correct



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information may be processed and integrated with the remainder of the text but this may happen in an encapsulated form (Boshuizen & Schmidt, 1992), with the new information forming an isolated cohort in the episodic memory of the text. As a consequence, although the correct information may be reproduced in direct tests about the textual information, it is unlikely that it will be accessed in other situations and, therefore, that transfer will take place. Put differently, the correct knowledge will have no or limited impact on the reader's performance and behaviour outside of this particular reading experience.

Furthermore, the findings demonstrate the important connection between on-line cognitive processes and off-line outcomes. The on-line processes in which readers engage form the basis for the construction of a mental representation based on the textual information (Goldman &Varma, 1995; Kintsch, 1988; Langston & Trabasso, 1998; Myers & O'Brien, 1998; van den Broek et al., 1999; Zwaan, 1999). Therefore, to be valid, conclusions about the processes that take place during reading should be consistent with the observations concerning the end-product of reading, and vice-versa. The findings from both the simulations and the empirical study assist in making the online–offline connection clear. The effectiveness of the refutation text as a means for conceptual change has been established using on-line evidence. In this study, we provided on-line evidence for the cognitive processes by which this happens, namely, through the co-activation of correct and incorrect conceptions during reading.

From a practical perspective, the findings suggest guiding principles for the development of methods for achieving conceptual change other than through text structure as well. In particular, they indicate that any strategy for bringing about conceptual change in students with misconceptions is considerably more likely to succeed if it creates a high likelihood of co-activation of misconceptions and correct conceptualizations. This suggests that the refutation format itself is neither necessary nor sufficient for creating co-activation. With respect to sufficiency, it is possible to create a refutation text in which misconception and correct knowledge are provided but not in a manner that is likely to elicit co-activation. This would occur, for example, if one presents the two pieces of conflicting information removed from each other and without ensuring that one is reactivated when the other is introduced. With respect to necessity, there may be other ways of encouraging co-activation. For example, text structures other than refutation could be used, such as compare-contrast and problem–solution. A compare-contrast structure typically presents the reader with two differing concepts and discusses their similarities and differences. A problem–solution structure typically opens with the discussion of a problem and then presents a recommendation for how that problem can be solved. Both structures have characteristics similar to that of a refutation text, namely they allow for the comparison and explanation of different ideas. The on-line effects of these structures on the reading by readers with misconceptions have not been studied, but information in compare-contrast and problem–solution structures has been found to be better recalled than information in other structures such as description or collection (Meyer, 1975; Meyer & Freedle, 1984). Given that the off-line text representation is often closely linked to the on-line processes during reading (Goldman & Varma, 1995; Kintsch, 1988; Langston & Trabasso, 1998; Myers & O'Brien, 1998; van den Broek et al., 1999; Zwaan, 1999), the superior recall may indicate stronger integrative processes which, in turn, may encourage conceptual change in the case of a reader with misconceptions.

Co-activation may also be accomplished through other means, for example by adding graphs or other illustrations that promote co-activation of conflicting knowledge and information or by specific activities designed to prompt students to activate their prior



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(erroneous) knowledge. For example, by signalling text locations with important information and instructing students to produce and make explicit their prior knowledge at those locations. Alternatively, one could instruct readers to activate their prior knowledge before reading the text as a whole. Evidence of the effectiveness of this latter approach—activating of students' background knowledge before reading—has been mixed (Alvermann & Hague, 1989; Alvermann, Smith, & Readence, 1985; Guzzetti et al., 1993). One reason may be that activating knowledge prior to reading in itself does not guarantee co-activation by the time that the correct information is encountered in the text.

In conclusion, a crucial first step in achieving conceptual change in students with misconceptions is to create a situation in which co-activation of misconception and correct conceptualization is likely. Whether a method for achieving this is successful will depend on how it modulates the fluctuations of activation during reading and, in particular, at the moment that the correct information is introduced. By creating a situation in which co-activation of misconception and correct conceptualization is likely, the chance of recognition of conflict and possible conceptual change is substantially increased. By considering the processing of readers' misconceptions and new, correct information in the context of a detailed cognitive-psychological model, such as the Landscape model, we gain a better theoretical understanding of the way in which a reader's prior knowledge and textual information interact and can derive direct practical applications for education and other circumstances in which conceptual change is desired.

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