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CICLO XXIV

FROM EYE FIXATIONS TO SCIENTIFIC CONCEPTUAL LEARNING:

A PROCESS APPROACH TO THE REFUTATION TEXT EFFECT

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Riassunto

La tesi si apre con la cornice teorica del lavoro di ricerca (Capitolo 1). In questa prima parte sono anzitutto presentati gli studi sul rapporto fra cambiamento concettuale e comprensione del testo, e i due modelli di comprensione del testo più rilevanti per l'apprendimento dal testo confutazionale, il *Construction-Integration (C-I) Model* (Kintsch, 1988) e il *Landscape Model* (van den Broek, Risden, Fletcher, & Thurlow, 1996). Successivamente è stata introdotta la recente ricerca sull'elaborazione specifica del testo confutazionale (es., Kendeou & van den Broek, 2007), nonché l'uso dei movimenti oculari nella ricerca sulla lettura, descrivendo come essi rappresentino un'efficace metodologia per studiare i processi online di comprensione dal testo (Hyönä, Lorch, & Rinck, 2003).

In seguito quattro studi sono presentati (Capitoli 2-5). Attraverso il primo studio si sono mostrate l'utilità e l'affidabilità della metodologia eye-tracking e sono stati raccolti risultati iniziali (Capitolo 2). Questi hanno suggerito come il testo confutazionale sostenga i lettori nell'attivazione delle proprie concezioni durante l'elaborazione iniziale del testo. Un conflitto concettuale può essere percepito durante la lettura del testo confutazionale (van den Broek & Kendeou, 2008), conflitto che richiede sforzo cognitivo per essere risolto (Sinatra & Pintrich, 2003). Infine, l'apprendimento dal testo confutazionale è risultato positivamente legato alla lettura strategica: la qualità, non la quantità della lettura influenza la comprensione profonda del testo. In altre parole, è cruciale come il tempo di lettura è speso.

Il secondo studio (Capitolo 3) ha esaminato se l'effetto del testo confutazionale comprenda diversi sottoprocessi con decorsi temporali differenti (il "quando" dell'effetto) e se tali sottoprocessi avvengano durante la lettura di parti di testo differenti (il "dove" dell'effetto). Questo studio ha evidenziato come l'effetto del testo confutazionale non sia monolitico, ma rappresenti piuttosto un effetto composito comprendente sottoprocessi distinti che si verificano in momenti diversi della lettura di parti di testo differenti.

Il terzo studio (Capitolo 4) ha analizzato la relazione fra l'effetto del testo confutazionale e l'elaborazione cognitiva durante le successive riletture di un testo scientifico. L'obiettivo di questo studio è stato di mostrare come il testo confutazionale influenzi il tipo di elaborazione durante le letture ripetute ampiamente descritto dalla ricerca (Hyönä & Niemi, 1990; Hyönä, 1995; Raney & Rayner, 1993, 1995). In particolare, lo studio ha messo in luce come il testo confutazionale riveli che il beneficio derivato dal rileggere sia, almeno parzialmente, di natura strategica.

Il quarto studio (Capitolo 5) si è focalizzato sulla memoria di lavoro verbale dei lettori (Burton & Daneman, 2007; Daneman & Carpenter, 1980). Nella fattispecie, questo studio ha analizzato, da una parte, se l'efficacia del testo confutazionale nel promuovere il cambiamento concettuale sia influenzata dalla diversa capacità di memoria di lavoro verbale dei lettori ("low-" e "high-span"); dall'altra, se l'elaborazione del testo confutazionale vari a seconda della capacità di memoria di lavoro verbale. I risultati di questo studio hanno evidenziato come l'effetto del testo confutazionale sia principalmente legato alla co-attivazione (Kendeou & van den Broek, 2007) delle concezioni corrette e scorrette sull'argomento in esame. Inoltre, il testo confutazionale facilita sia i lettori con basso span sia quelli con span alto nell'elaborazione delle informazioni. Infine, i lettori con un più basso span di memoria di lavoro verbale apprendono di più dal testo confutazionale rispetto al testo non confutazionale.

La tesi si chiude con un capitolo finale (Capitolo 6) in cui è presentata la discussione generale dei risultati emersi nei vari studi e sono indicate alcune possibili direzioni della ricerca futura.

Summary

The thesis starts with the theoretical framework of the research work (Chapter 1). First, the studies that have investigated the relationship between conceptual change learning and text comprehension are introduced, as well as the two models of text comprehension that are particularly relevant to learning from the refutation text, the *Construction-Integration (C-I) Model* (Kintsch, 1988) and the *Landscape Model* (van den Broek, Risden, Fletcher, & Thurlow, 1996). Then, recent research that has dealt with the specific processing of refutation text (e.g., Kendeou & van den Broek, 2007) is reviewed. Finally, I described the use of eye movements in reading research, explaining how they represent an effective methodology to tap into the moment-to-moment online comprehension processes at discourse level (Hyönä, Lorch, & Rinck, 2003).

Following, four studies are extensively presented (Chapters 2-5). The first was a study in which the usefulness and reliability of the eye-tracking methodology was tested, and initial evidence has been collected (Chapter 2). Findings from this study suggested that the refutation text assists readers to activate their current conceptions during the initial text processing. A conceptual conflict may be perceived during refutation text reading (van den Broek & Kendeou, 2008), requiring an intentional cognitive effort to be resolved (Sinatra & Pintrich, 2003). Finally, learning from the refutation text was positively related to strategic reading: the quality, not the quantity, of reading is entailed in deep text comprehension. In other words, it is crucial how the reading time is spent.

The second study has addressed the issue of whether the refutation text effect encompasses a series of sub-processes with different time courses (the “when” of the effect), taking place on different parts of the text (the “where” of the effect) and at different stages of reading (Chapter 3). This study provided evidence that the refutation text effect is not monolithic; rather, it represents a

composite effect comprehending sub-processes that take place in different parts of the text and at different stages of reading.

The third study has investigated the relationship between the refutation text effect and text processing during repeated exposure with text information. The aim of this study was to reveal that the refutation nature of a text alters the well-established (Hyönä & Niemi, 1990; Hyönä, 1995; Raney & Rayner, 1993, 1995) pattern of processing during repeated reading (Chapter 4). This study particularly showed that repetition benefits are, at least in part, strategic in nature.

Finally, the fourth study has been focused on the readers' verbal working memory capacity (Burton & Daneman, 2007; Daneman & Carpenter, 1980). Specifically, it has investigated, on the one hand, whether the effectiveness of the refutation text in promoting a stronger conceptual change would be different in readers with diverse working memory capacity (lower- and higher-span readers); on the other hand, whether refutation text processing at discourse level would vary as a function of the readers' working memory capacity (Chapter 5). Findings from this study showed that the refutation text effect is mainly related to the co-activation (Kendeou & van den Broek, 2007) of incorrect and correct conceptions about the examined phenomenon. The refutation text also facilitates the processing of text information for both lower- and higher-span readers. Readers with a lower working memory capacity span learn more when interacting with the refutation text rather than with the standard one.

The thesis concludes with a final chapter (Chapter 6), which presents a general discussion of the findings emerged across the studies and indicates some potential future direction of the research.

Chapter 1

Introduction

Research on conceptual learning has documented that classroom learning often requires the restructuring of existing knowledge. It has also revealed that such a restructuring is rather difficult to achieve and students often fail to understand complex disciplinary concepts. Different theoretical frameworks have been proposed to describe what changes in conceptual change (Chi, 1992; Halldén, 1999; Vosniadou, 1994; Säljö, 1999), as well as instructional activities to promote it (Duit, 2007; Hatano & Inagaki, 2003; Mason, 2001; Mikkilä-Erdmann, 2002). In addition, after the seminal work by Pintrich, Marx, & Boyle (1993), some studies went further than only considering cognitive factors and took into account the affective, motivational, and social/contextual aspects that may affect knowledge revision (Sinatra & Pintrich, 2003). Recent research has pointed out the complex and delicate interplay of multiple factors that play a role in yielding conceptual learning (Murphy & Mason, 2006; Sinatra & Mason, 2008; Vosniadou, 2008; Vosniadou & Mason, 2012).

Most of the conceptual learning that takes place in school and academic contexts occurs through effective text reading. Success or failure during text comprehension depends on multiple factors, which may be related both to readers' characteristics and text properties (Goldman & Bisanz, 2002). Among readers' characteristics, an essential role is played by the quality of their prior knowledge, that is, the accuracy of what they already know about a specific topic. It has been documented that students' misconceptions act as constraints in learning from text (e.g., Kendeou & van den Broek, 2007).

Authoritative scholars (e.g., McNamara, 2001; McNamara & Kintsch, 1996; Ozuru, Dempsey, & McNamara, 2009) have suggested that text comprehension is affected by the interaction between reader's prior knowledge and text characteristics. In other words, the nature of the text to be studied contributes to the influence on conceptual understanding. Different ways are suitable to organize concepts and ideas in texts, resulting in different text types (Graesser, Leon, & Otero, 2002). With this regard, a particular type of text, the refutation, has been shown to be more effective than a standard, non-refutation text in promoting knowledge restructuring (Diakidoy, Kendeou, & Ioannides, 2003; Guzzetti, Snyder, Glass, & Gamas, 1993; Hynd, 2003; Mason, Gava, & Boldrin, 2008; Mikkilä-Erdmann, 2002). Refutation texts have been largely studied by educational and reading research in the past twenty years (see Guzzetti, Snyder, Glass, & Gamas, 1993; Tippett, 2010, for reviews). It is generally agreed upon how to define what a refutation text is: a refutation text is a text that, first, clearly states the misconceptions a reader may hold about a particular topic, especially in science domains. Following, it challenges such misconceptions by explicitly refusing them. Finally, it provides the currently accepted scientific explanation for that topic.

Until recently, the focus of the research employing refutation texts has been on the offline products of comprehension, namely, whether a refutation text is more effective than a standard text in enhancing better comprehension outcomes. With this respect, research has documented that the refutation text is actually more effective, for example in learning physics (Hynd, 1998) and biology concepts (Mikkilä-Erdmann, 2002), for students of elementary (e.g., Mason, Gava, & Boldrin, 2008), middle (e.g., Mason & Gava, 2007), and high school (e.g., Qian & Pan, 2002), as well as college students (e.g., Chambers & Andre, 1997).

Why are refutation texts more powerful than standard texts? It has been posited that the superiority of refutation texts may be related to their comprehensibility and the multiple evidence they provide to support the central argument (Murphy, 2001). With respect to the text genre, it has also been pointed out that refutation texts may be considered as a kind of persuasive text, since they help learners identify with the information being read, create cognitive dissonance between the readers' current ideas and the new information being read, and are understandable, plausible, and useful (Hynd, 2001).

Much lesser is known about the processing of refutation texts, namely, whether the processes of reading a refutation text significantly differ from those of a standard text. In the last years, several attempts have been made to fix this lack, particularly by investigating the so-defined "refutation text effect" on the basis of the peculiar kind of reading processing the refutation text would prompt (Broughton, Sinatra, & Reynolds, 2010; Kendeou & van den Broek, 2007; van den Broek & Kendeou, 2008).

The aim of this thesis is twofold: (1) to study the refutation text effect, namely, the peculiar effect induced by a refutation text on the online cognitive processing during reading and (2) to investigate whether different learning outcomes (offline products) produced by reading a refutation text are related to different cognitive processes (online measures). Specifically, the current research work, which is at the intersection of conceptual learning and reading comprehension research (Sinatra & Broughton, in press), adopts a process approach based on the analysis of the eye-movement behavior during reading to investigate the refutation text effect.

The outline of this theoretical introduction is as follows. First, I introduce the seminal studies that have investigated the relationship between conceptual change learning and text comprehension. I then examine the two models of text comprehension that are particularly relevant to the learning from the refutation text, the *Construction-Integration (C-I) Model* (Kintsch, 1988; 1998) and the *Landscape Model* (van den Broek, Risden, Fletcher, & Thurlow, 1996; van den Broek, Young, Tzeng, & Linderholm, 1999). Following, I review the recent research that has dealt with the peculiar processing of refutation text (Broughton et al., 2010; Kendeou & van den Broek, 2007; van den Broek & Kendeou, 2008; van den Broek, 2010). Finally, I introduce the use of eye movements in reading research and explain how they represent an effective methodology to tap into the moment-to-moment online comprehension processes at discourse level (Hyönä & Lorch, 2004; Hyönä et al., 2003; Rayner, 1998, 2009).

1.1. Scientific Conceptual Learning and Text Comprehension

Research has shown that the comprehension of science texts can be quite challenging for learners (e.g., Chambliss, 2002). One of the main claims is that the students' inaccurate prior knowledge about a particular topic hinders text comprehension at different ages (Chi, 1992; Dole & Sinatra, 1998; Vosniadou, 1994). A great deal of research has dealt with the role played by the "quantity" of students' prior knowledge in influencing the comprehension of science texts, and a lot of evidence has been collected. For example, it has been documented that readers with high knowledge about the topic introduced in the text are advantaged over readers with low prior knowledge (Chiesi, Spilich, & Voss, 1979; Dochy, Segers, & Buehl, 1999; Means & Voss, 1985; Recht & Leslie, 1988). However, not only the quantity but also the "quality" of students' prior knowledge impacts on learning from text. Quality refers to the accuracy of knowledge and has been mostly investigated with respect to students' inaccurate ideas in science (e.g., Kendeou, Rapp, & van den Broek, 2004; Kendeou & van den Broek, 2005, 2007). With this respect, educational researchers and cognitive scientists who deal with the issue of conceptual learning have widely documented that, from the viewpoint of quality of knowledge about science, students' prior knowledge may include alternative conceptions, namely, misconceptions about scientific phenomena (Carey, 1985; Chi, 1992; Vosniadou & Brewer, 1987). Such misconceptions have been found to interfere with the acquisition of new knowledge from text (Diakidoy & Kendeou, 2001; Maria & MacGinitie, 1987). In other words, students' misconceptions would act as a barrier, hindering the achievement of a successful comprehension from text for readers who hold them (Murphy & Mason, 2006). As a direct consequence, when misconceptions about a specific science topic are present, a successful comprehension of the text implies the revision of the inaccurate prior knowledge. This, in turn, clarifies that learning from science texts should not be viewed as a mere question of accumulating new knowledge; rather, it should be conceived as a question of actively restructuring the pre-existing knowledge, that is, to turn it into the right scientific explanations (Dole & Sinatra, 1998). Unfortunately, such a knowledge restructuring has been shown as quite difficult to achieve (Chi, 1992; Chinn & Samarapungavan, 2001; Vosniadou, 1994), since multiple factors play a role in this process. These factors are related to the cognitive and motivational characteristics of students as well as to the text features (Murphy & Mason, 2006; Sinatra & Mason, 2008; Sinatra & Pintrich, 2003; Vosniadou, 2008; Vosniadou & Mason, 2012). Given that text characteristics, for instance its refutation nature, can influence learning from text, these have to be recognized as playing a crucial role in conceptual change learning.

What is the relationship between learning of scientific concepts and text comprehension? Learners need to fully comprehend the scientific explanations presented in the text to be able to revise their misconceptions (Rukavina & Daneman, 1996). Despite the many and different theoretical approaches to the study of conceptual change (see Vosniadou, 2008), most researchers agree that students have ideas from their everyday experience that contrast the scientific explanations of natural phenomena. A classical example regards learning about the shape of the Earth (Vosniadou & Brewer, 1992, 1994). The notion of the Earth as spherical is particularly challenging. There is a series of reasons for such a challenge. First of all, students' everyday experience conflicts with this notion. Second, their experience with a globe or ball indicates that objects cannot stay still if placed on a sphere, but they fall off rapidly as the sphere, for example, rotates. Finally, ideas like that of the Earth's shape are tightly interconnected to many other ideas or concepts (e.g., the concept of gravity and day/night cycle). As a matter of fact, concepts are not single pieces of knowledge, fragmented and separated each other; rather, they are embedded in what can be referred to as a "conceptual ecology" of the students' knowledge (Posner, Strike, Hewson, & Gertzog, 1982).

Posner and colleagues (1982) have proposed a well-known model of conceptual change that exerted a strong influence on the successive research in this field. In this model, four are the possibilities when learners encounter new information in a text. However, only one of them results in conceptual change. The first possibility is when the new information is not counterintuitive. In such a learning situation, that information can be easily assimilated into the students' pre-existing knowledge structures. In contrast, if the new information directly contradicts learners' prior knowledge, there are three possibilities: the information is rejected; the information is encapsulated into a new knowledge structure, which is separated from what was already known; prior knowledge is restructured to fit the new information. As it appears evident, only the last possibility results in conceptual change. Posner and colleagues (1982) also outlined four conditions for conceptual learning to occur: (1) prior knowledge must be identified as inadequate and (2) the new information must be understandable, (3) useful and plausible in solving the current knowledge problem, (4) and fruitful in solving future problems. The model proposed by Posner and colleagues (1982) is particularly relevant since it provided the theoretical framework for early research on refutation text research (e.g., Hynd & Alvermann, 1986a, 1986b). On the basis of the theoretical claims of this model, educational researchers and cognitive scientists have started to examine the use of refutation text to enhance conceptual change learning.

However, the process of conceptual change has not only been studied from the cognitive point of view. Ontological perspectives have also been adopted in order to account for it. For example, the theory proposed by Chi, Slotta, and de Leeuw (1994), in which the nature of ontological categories, science concepts, and naïve conceptions are presented as important factors that influence learning, emphasize how the learners conceptualize the nature of scientific concepts.

There are many scientific ideas that, like the shape of the Earth, contradict students' everyday knowledge. As noted above, conceptual learning is not easy to achieve, since scientific ideas are complex and challenging to understand. For example, the idea that the objects are made up of a myriad of invisible parts called molecules may be difficult for students to believe. Other topics, such as evolution (Sinatra, Brem, & Evans, 2008; Sinatra, Southerland, McConaughy, & Demastes, 2003), seasonal change (Broughton et al., 2010), or even the phenomenon of ocean tides (Sawicki, 1999; Viiri, 2000) can be difficult for learners. The process of text comprehension basically consists in connecting the background knowledge and new information provided in the text, that is, the text content. It is thus clear that a text that challenges learners' background knowledge, which may comprise misconceptions, can also be particularly effective in promoting conceptual learning.

1.2. Models of Text Comprehension

Text comprehension is a complex cognitive process that involves both lower (e.g., decoding) and higher-level processing of information in order to extract meaning from text (McNamara & Magliano, 2009). Multiple models of text comprehension have been proposed (see Goldman, Golden, & van den Broek, 2007, for a review). Two models of text comprehension are particularly relevant to conceptual change and learning from the refutation text: the *Construction-Integration Model* (Kintsch, 1988; 1998) and the *Landscape Model* (van den Broek et al., 1996; van den Broek et al., 1999). These models are important since they highlight the connection between text comprehension and learning: they emphasize the activation of the reader's relevant background knowledge during reading as well as the role of the reader in building a coherent model of the text information. Specifically, these models posit that as the readers process information in the text, their prior knowledge, which may include misconceptions, is activated. As the readers continue to process the text information, they may recognize an inconsistency between their prior knowledge and the ideas in the text, which, in turn, increases the likelihood of conceptual change. The Construction-Integration Model and the Landscape Model are presented in details in the next sections.

1.2.1. The Construction-Integration Model

The Construction-Integration (C-I) Model (Kintsch, 1988, 1998) posits that different and subsequent levels of memory representations are generated as part of the comprehension process. In the most recent development of the model (Kintsch, 1998), text comprehension mainly consists of two stages. The first is the *construction* phase, a bottom-up process that arises from the linguistic input and corresponds to the building of the *textbase*. The textbase corresponds to the propositional representation of the text. It is constructed by maintaining the explicit propositions (included in each sentence) but ignoring the *surface code* (van Dijk & Kintsch, 1983), which comprises the syntax and wording of each sentence. The second stage is the *integration* phase, a top-down process in which the meaning of the text interacts with the readers' prior knowledge in constructing the *situation model*, usually referred to as the mental model of the text. The situation model is the representation of the text that results from the integration of the content of the text and the reader's prior knowledge (Kintsch, 1988). The entire process, as described by the Construction-Integration Model, takes place as follows: the reader proceeds through the text; concurrently, the information is parsed into phrases. As each sentence or phrase is read, it passes through a construction phase and then an integration phase.

The reader's prior knowledge plays a central role in the C-I model. In Kintsch's view (1988, 1998), prior knowledge acts as a map that strengthens the links among the concepts that are most important to comprehension and, at the same time, it weakens the pointless connections. Knowledge is conceived as a net in which concepts or propositions are the nodes. As a text is read, one sentence at a time, a set of concepts is activated. The activation level of concepts fluctuates systematically as the reader proceeds through the text. The activated concepts include those that are explicitly and inferentially activated by the sentence, as well as concepts that are preserved active in working memory, for example those from the previous sentence. These concepts form a cluster of propositions that is derived from "a context-free process of activation of the closest neighbors of the original text-driven proposition in the general knowledge net" (Kintsch, 1988, p. 180). The resulting cluster of concepts may include irrelevant concepts. However, additional activation of concepts in the network typically results in excluding the irrelevant concepts from further processing. The resulting memory representation is a coherent representation of the text integrated with the reader's prior knowledge.

One of the main contributions of Kintsch's work is to have shed light on the crucial relationship between text comprehension and learning. Only deep comprehension produces learning from text: good comprehenders, after constructing a stable situation model from text, are able to manipulate the information read and use them to their purposes, for instance to generate inferences. As a matter of fact, it is the construction of the situation model that is central to text comprehension (Kintsch, 1986) and that plays an important role in conceptual learning.

1.2.2. The Landscape Model

The second model of text comprehension that is relevant to our purposes, the Landscape Model (van den Broek et al., 1996; van den Broek et al., 1999), is even more specific to the relationship between comprehension and conceptual learning than the Construction-Integration Model. Moreover, it has also been proved to provide insights into the specific processing of refutation text and learning from this type of text (e.g., Kendeou & van den Broek, 2007; van den Broek & Kendeou, 2008). The Landscape Model posits that, as the readers proceed through the text, the concepts included in the various sentences are processed in cycles. However, due to the limited capacity of working memory, readers can only process a subset of the concepts at any given time. The authors point out (van den Broek & Kendeou, 2008) that, as the readers proceed through the text, concepts (e.g., propositions, informational units) continue to fluctuate in activation: in each new cycle some concepts keep on being active whereas others decline in activation. Moreover, it is possible that some concepts are reactivated. Four are the sources of information that influence the fluctuations in concept activation: (1) text information in the current processing cycle, (2) residual text information from the previous cycle (e.g., the preceding informational unit), (3) the text representation constructed until that moment, and (4) the readers' prior knowledge, which may include misconceptions. Due to these distinct sources of activation and readers' limited working memory capacity, the conceptual information continually fluctuates in activation during reading.

The Landscape Model also postulates that two types of cognitive mechanisms drive the activation of concepts from the readers' prior knowledge on the one hand, and from the memory representation of the text constructed thus far on the other. The first mechanism is *cohort activation (co-activation)*, which is the process by which concepts that are associated with the currently activated concept are also activated. In other words, when a particular concept is activated, the readers may activate associated concepts that are already stored in their prior knowledge. The kind of processing corresponding to the co-activation is text-driven and occurs automatically, that is, it is unconscious and does not require efforts on the part of the readers (van den Broek & Kendeou, 2008).

The second mechanism is the so-defined *coherence-based retrieval*. In contrast to the automatic nature of co-activation, coherence-based retrieval is intentional and strategic, employed by the readers to construct a coherent representation of the whole text. The process of coherence-based retrieval takes place online, as the readers seek information from either the text representation constructed thus far or their prior knowledge during reading (van den Broek & Kendeou, 2008).

The execution of co-activation processes or coherence-based retrieval processes is, at least in part, controlled by the readers' *standards of coherence*. Standards of coherence represent the standards for what the readers consider as adequate comprehension (van den Broek & Kendeou, 2008). If the information activated at each cycle meets the readers' standards of coherence, reading continues without particular disruptions and employing retrieval strategies is not necessary. In contrast, when co-activated concepts do not meet the readers' standards of coherence, the reader may use strategies to maintain an adequate level of comprehension, for example by actively searching the text-based mental representation produced thus far.

Within the framework provided by the Landscape Model, the patterns of activation are crucial to understand how the readers achieve a full comprehension of the text. In the process of comprehension, the particular concepts that are activated at each reading cycle are added to the developing text representation. Therefore, when a concept is reactivated during reading its memory trace is strengthened.

Among the aforementioned processes, the process of co-activation provides insights into the link between reading comprehension, misconceptions, and conceptual change learning. As a matter of fact, it is evident that only the concepts that are co-activated can be compared and used for further processing and integration (van den Broek & Kendeou, 2008). The co-activation of misconceptions and scientifically correct concepts increases the likelihood that the readers notice the discrepancy between the two, which in turn may facilitate the revision of the inaccurate ideas (Guzzetti et al., 1993; Kendeou & van den Broek, 2007). Thus, the co-activation represents a process potentially relevant to the refutation text effect and it may contribute to explaining the more effectiveness of the refutation text in promoting conceptual learning. Recently, co-activation as a process component of the refutation text effect has started to be empirically investigated by using think-aloud protocols, reading time, and computational data (Kendeou, 2009; Kendeou & van den Broek, 2007; van den Broek & Kendeou, 2008).

1.3. Processing the Refutation Text

As stated above, a refutation text is an expository text that acknowledges the misconceptions a reader may hold about a topic, explicitly refutes them, and presents the scientific explanations as viable alternatives (Alvermann & Hague, 1989; Hynd, McWhorter, Phares, & Suttles, 1994; Hynd, Qian, Ridgeway, & Pickle, 1991; see Guzzetti et al., 1993; Tippett, 2010, for reviews). In particular, three structural components of a refutation text have been defined (Guzzetti, 2000; Maria & MacGinitie, 1987; Tippett, 2010): (1) The statement of the misconceptions a reader may hold about the topic presented in the text, (2) a signal or cue that alerts the reader to the possibility of another explanation, followed by (3) the statement of the currently accepted scientific explanation. As defined, the first two components could be properly referred to as the "refutation statement". In contrast, a standard text only provides the new scientific information. As it appears evident, the main difference between a refutation and a standard, non-refutation text is that in the refutation text the readers' misconceptions concerning the learning topic are signaled by refutation statements, whereas in the standard text they are not.

In the last years, several studies have proposed that the refutation nature of a text affects online processing during reading. These studies have made use of thinking aloud and reading time measures (Kendeou & van Broek, 2007), only computational simulations (van den Broek & Kendeou, 2008), and, more recently, eye-fixation measures. The main claim across these studies is that specific types of text processing at discourse level (Hyönä, Lorch, & Rinck, 2003) take place while learning from a refutation text: research has shown a facilitation effect while reading the parts of the text where the refutation statements are introduced (Broughton et al., 2010), a more strategic reading behavior on the segments of text introducing the scientific information, and a stronger co-activation during the reading of refutation parts (Kendeou & van den Broek, 2007; van den Broek & Kendeou, 2008).

Broughton and colleagues (2010) examined the relationship between conceptual change learning and time spent reading a refutation text. Undergraduate students read either a refutation text or a standard text on the causes of seasonal change on Earth. Participants' sentence-by-sentence reading times were recorded. Returning to previously read sentences was prevented. Thus, only the first-pass reading of the text was monitored. Results showed, first, that participants who read the refutation text had fewer misconceptions at posttest than participants who read the expository text. Further, findings concerning the reading processing showed that readers processed the two types of texts differently. Specifically, participants read the refutation segment significantly faster than the corresponding sentences in the standard text. The authors interpreted their findings as consistent with research on text processing and interest. When readers find a text segment particularly interesting, they can show faster reading times (Lehman, Schraw, McCrudden, & Hartley, 2007). It is possible that refutation signals, highlighting possible inconsistencies between readers' prior conceptions and text information, made text information more interesting to attend; this higher interest is reflected in facilitated processes indexed by shorter sentence-by-sentence reading times, namely, a faster first-pass reading of the text.

Kendeou and van den Broek (2007) carried out a study that included two experiments to investigate the interaction between readers' prior knowledge and type of scientific text (refutation vs. non-refutation), as well as its effect on comprehension. They also considered the influence of two readers' characteristics, working memory capacity and need for cognition. The purpose of the whole study was to document how online cognitive processes affect comprehension products. To test their hypotheses, the authors used two different methodologies: the analysis of thinking-aloud protocols and reading times. Data from both experiments showed that the online interaction between readers' prior knowledge and text structure directly influences the comprehension outcomes, underlying the role played by online cognitive processes in the construction of a consistent situation model from text.

In a following study, van den Broek and Kendeou (2008) explained the more effectiveness of the refutation text in promoting conceptual change learning by pointing out that the refutation statements serve as advanced organizers for the comprehension process and that during the reading of a refutation text the co-activation is stronger. Co-activation refers to the simultaneous activation of correct and incorrect ideas, which is associated with the detection of inconsistencies and knowledge revision activities (Kendeou & van den Broek, 2007; van den Broek & Kendeou, 2008; van den Broek, 2010). Co-activation implies a deeper cognitive processing of the refutation text. The authors tested the role of co-activation during the reading of the refutation text by carrying out a computational simulation and an experiment using reading times. Results from the computational simulation by the Landscape Model and the experiment were consistent and supported the idea that the co-activation is a crucial process during the reading of a refutation text for a better comprehension of scientific concepts.

In trying to investigate both the online processes that take place during text reading and offline products of comprehension after reading, these studies opened a new line of research in the fields of text processing, text comprehension, and learning from text. However, their seminal contribution may be further investigated by adopting more precise indicators of cognitive processing during the reading of a refutation text. Thinking aloud actively disrupts the process of comprehension, requiring students to allocate cognitive resources away from the experimental task. On the other side, cognitive processing measured by means of reading times of single sentences presented one at a time is different from the elaboration of a whole text. A possible direction of new investigations may be toward a measure of cognitive processing during refutation text reading that overcome the methodological limitations of thinking aloud and reading times, to account for the more effectiveness of refutation text in promoting conceptual learning.

To extend current research, the studies presented in this thesis aimed to investigate the refutation text effect to see whether different outcomes (offline measures) produced by reading a refutation or a non-refutation text are related to different cognitive processes (online measures). The common added value of these studies was that they relied on eye-tracking methodology, which provides quantitative and objective data about cognitive processing during reading. Eye tracking was then used in trying to connect processes and products of learning from text. As a matter of fact, the link between eye fixations and cognitive processing is quite close, especially in complex information processing tasks, such as reading (Just & Carpenter, 1980; Rayner, 1998, 2009). Among online methodologies, eye tracking provides several indices of cognitive processing that can be collected at the same time with high temporal and spatial resolution. In addition, eye tracking does not disrupt reading as other online methods (e.g., thinking-aloud).

1.4. Eye Movements and Comprehension Processes in Reading

1.4.1. Basic Characteristics of Eye Movements during Reading

Two are the major components of eye movements during reading: fixations and saccades; regressions, which are a particular subclass of saccades whose direction is from right to left, also represent an important component (see Rayner, 1998, 2009, for reviews). Although, on the basis of introspection, it can appear that the eyes move smoothly across the page of text during reading, the reality is that the readers make a series of discrete movements, the saccades, from one place to another in the text. These movements are separated by pauses, the fixations, whose variability in duration can be represented by a right-skewed normal distribution with the mean at around 200-250 milliseconds and minimum and maximum at about 50-100 and 500 milliseconds, respectively (Staub & Rayner, 2007).

Fixations are the only periods of time when the new information is encoded, since the cognitive processing is suppressed during saccades. The eyes of skilled readers typically move about seven to nine letter spaces with each saccade. However, the values mentioned above (200-250 milliseconds for fixations and seven to nine letter spaces for saccades) are averages, and there is large variability in both these measures. Much of the variability in the measures is related to the ease or difficulty of understanding the text as a whole (Rayner, 1998; Rayner & Slattery, 2009): as text becomes more difficult, fixations get longer and saccades get shorter. About 10 to 15% of the time, skilled readers make a regression (a saccade that moves the eyes backward in the text, as indicated above). Readers launch regressions in order to reread the text, namely, to process once more the information that they have previously encountered. As fixations get longer and saccades get shorter as the text becomes more difficult, readers make more regressions because reading is difficult.

Several theorists (Hyönä, Lorch, & Rinck, 2003; Liversedge, 2003; Liversedge & Findlay, 2000; Rayner, 1998, 2009) have pointed out that eye-movement data are highly informative with respect to the understanding of reading. As eye movements, particularly eye fixations, are a natural part of the reading process, they provide a valuable moment-to-moment indicator of the online processes that take place during reading. In sum, information about where readers fixate in the text and how long they look at different part of it provides reliable data about comprehension at a number of levels, from lexical to discourse processing (Rayner et al., 2006; Rayner & Slattery, 2009).

About thirty years ago, Just and Carpenter (1980) provided a new theory of reading based on the relationship between eye-fixation data and comprehension of students who read passages from a scientific text. The new framework proposed was a complex model including text processing as revealed by eye movements, as well as working and long term memory. In this account, two were the main assumptions for the link between eye movements and text comprehension. The first was the *immediacy assumption*, which posits that the interpretations at all levels of processing are not deferred and occur as soon as possible. The second was the so-called *eye-mind hypothesis*. According to this assumption, there is a close relationship between the direction of human gaze and the cognitive processing during the reading of a text. In other words, the duration of fixations on words and larger segments of text directly reflects the information encoding. The authors discussed possible investigations about their theoretical claims, suggesting two main directions: the construction of computer simulations that are driven by reading performance data and the design of new empirically researches to study the real-time characteristics of reading (Just & Carpenter, 1980).

An example reported by Staub and Rayner (2007) helps to clarify the Just and Carpenter's (1980) question of the "eye-mind span", that is, how big is the lag between the eyes and mind. The authors (Staub & Rayner, 2007) explained that when readers read a text loudly, if the lights in the room are switched off, they are still able to produce two or three words after the lights have been turned off. This is because there is an "eye-voice span": the eyes are ahead of the voice by a few words. Does an "eye-mind span" for which the eyes are ahead of the mental processing associated with reading exist the same way, or the link between eyes and mind is tighter? Staub and Rayner (2007) concluded that even though that link is not perfect since there are preview (when readers have a valid preview of the next word to the right of fixation, they look at it for about 30-50 ms less time than if they have no preview of the word) and spillover effects (the processing associated with a given word can sometimes spillover onto the next word in the text), how long readers look at a word, a sentence, or an entire text is generally a reliable reflection of the immediate processing time associated with that word, sentence, or text.

1.4.2. Eye Movements and Global Text Processing

In recent years, Hyönä and colleagues (Hyönä & Lorch, 2004; Hyönä & Nurminen, 2006; Hyönä et al., 2002; Kaakinen, Hyönä, & Keenan, 2003; see Hyönä et al., 2003, for a review) have documented that eye-tracking methodology is very useful in studying the so defined "global text processing", a particular kind of reading processing that takes place at discourse level. As these authors have pointed out, global text processing refers to processes that identify relationships between segments of text information that are not adjacent, not including mental processes related to building local coherence between consecutive sentences. As described, global text processing represents a kind of processing of particular interest, since it is implied in the process of knowledge restructuring while learning from text, for instance a refutation text.

Eye-tracking methods (Rayner & McConkie, 1976) have been extensively used to learn about "early" processes in reading, including basic questions concerning word processing (e.g., lexical access and perceptual span), syntactic parsing, and simple inter-sentential processing (e.g., anaphora resolution). Nevertheless, the use of eye movements for capturing the processing of reading is not so common in educational psychology research. As fixations analysis was largely used to explore more basic processes, as those just aforementioned, most used indices (e.g., gaze duration on a target word or probability of fixating a specific sentence within the text) are not directly suitable to study materials relevant to educational research, for example the refutation text. So, researchers have not fully explored the potential of eye-tracking methodology, even though there has recently been increased interest in this methodology, especially in research about multimedia learning (Mayer, 2010; Scheiter & van Gog, 2009; van Gog & Scheiter, 2010) and expository text reading (Hyönä et al., 2002; Hyönä & Nurminen, 2006). In particular, the methodology has been used only infrequently to investigate global text processing (Blanchard & Iran-Nejad, 1987; Hyönä, 1995; Hyönä et al., 2002; Shebilske & Fisher, 1983; Vauras, Hyönä, & Niemi, 1992).

Eye tracking is particularly attractive as a method for studying global text processing for several reasons. First, it allows the investigation of online processing. Second, it allows collecting several indices of processing with both high temporal and spatial resolution. Third, eye tracking does not disrupt normal reading as many online methodologies do (e.g., thinking-aloud protocols). Within a display screen, the readers are free to examine any part of the text in any order, and they are never interrupted with a secondary task.

Hyönä and associates (Hyönä & Lorch, 2004; Hyönä et al., 2003; Kaakinen et al., 2003; Hyönä et al., 2002; Hyönä & Nurminen, 2006) indicated a series of indices for the treatment of eye-fixation data. They have been shown to be effective in capturing various aspects of reading processing at discourse level (such as global text processing) and, thus, excellent tools for educationally relevant eye-tracking research on text. In particular, Hyönä and colleagues have monitored the time course of reading processing at discourse level by examining two distinct and subsequent stages of processing, as delineated in the eye-fixation records: *first-pass reading* and *second-pass reading*. *First-pass reading* consists of all fixations landing on a target segment when it is read through for the first time, hence, before exiting it to the right. Within the first-pass reading, two different types of fixations can be further distinguished: forward fixations and reinspective fixations. Forward fixations are fixations that land on unread regions of a target segment during its initial reading; on the other hand, reinspective fixations are fixations that land on already processed portions of the target segment, still during its initial reading. Second-pass reading includes all the fixations made after the first-pass reading. *Second-pass reading* fixations are analyzed by taking into consideration both the origin and destination of the sequences (see Hyönä et al., 2002; Hyönä et al., 2003). In particular, look-back fixations index the destination of these fixations, whereas look-from fixations reveal their origin. In other words, *look-back fixations* are fixations *to* a sentence from another sentence, whereas *look-from fixations* are fixations *from* a sentence to another sentence. The former measure reflects the time taken to reprocess a text segment, whereas the latter measure provides an index of the extent to which a text segment is used as an "anchor point" for processing other text segments. With respect to the time course of text processing at discourse level, the first-pass reading fixations index more immediate effects in processing, whereas the second-pass reading fixations reflect more delayed effects.

Empirical research carried out by Hyönä and colleagues (e.g., Hyönä & Lorch, 2004; Kaakinen & Hyönä, 2007; Kaakinen et al., 2003; Hyönä et al., 2002; Hyönä & Nurminen, 2006) has documented the significance and usefulness of eye fixations to understand the complex aspects of online text processing, aspects that are relevant to educational psychology research. For example, Hyönä and colleagues adopted eye-fixation measures to identify reading strategies of individuals as they read multiple-topic expository texts (Hyönä et al., 2002; Hyönä & Nurminen, 2006) and to examine how some individual differences, such as prior knowledge, working memory capacity, and relevance of information, affect text processing at discourse level (Kaakinen & Hyönä, 2007; Kaakinen et al., 2003).

In a study with competent adult readers reading a multiple-topic expository text (Hyönä et al., 2002), four types of reading strategies were identified with their distinctive features. They differed according to the ways in which readers reprocess the text. Fast linear readers did not make return fixations on previous text. Slow linear readers made many reinspections before moving on, as well as many forward fixations. Non-selective reviewers were readers that made many look-backs to previous sentences. Finally, topic structure processors were specific in looking back intensively the headings that accompanied the text and produced the most accurate text summaries.

Processing of expository text during repeated reading was also examined in relation to perspective instructions or reading goals (Kaakinen & Hyönä, 2007). University students read twice, from a given perspective, either a high (familiar diseases) or low prior knowledge (rare diseases) text, and switched perspective before the third reading. Findings showed that cognitive processing, as indexed by eye fixations, was influenced by prior knowledge and reading perspective. The latter impacted the first-pass reading, while the former helped the recognition of (ir)relevant text information and supported the generation of earlier perspective effects while reading the high prior knowledge text. In addition, text processing was facilitated by repeated reading, as indicated by all the eye-fixation measures. After switching perspective, a repetition effect emerged for previously relevant text information. In contrast, a repetition cost was found for previously irrelevant text information.

In a following study by Hyönä and Nurminen (2006), both eye fixations and verbal reports were examined to investigate the role of individual differences in reading styles among competent adult readers, as well as readers' awareness of their learning styles. The authors were interested in analyzing the extent to which participants' actual reading behavior corresponds to their reported reading behavior, measured by means of a questionnaire. A cluster analysis carried out on eye-fixation data revealed three types of reader. Based on the distinction emerged in a previous study (Hyönä et al., 2002), they were defined as fast linear readers, slow linear readers, and topic structure processors. Correlations between eye-fixation measures and verbal reports indicate appreciable participant awareness of reading speed, as well as a fair awareness of their look-backs and rereading behavior. The quality of recalls of the main ideas presented in the text also correlated with the amount of time devoted to looking back the text about endangered species (Hyönä & Nurminen, 2006). Particularly relevant for research on learning from text is the issue that look-back fixation time can provide an index of purposeful and strategic behavior during reading.

From all this evidence, it appears quite evident that global text processing is implied in the process of learning from text. With this regard, Mikkilä-Erdmann, Penttinen, Anto, and Olkinuora (2008) carried out the first exploratory study measuring eye fixations to trace conceptual change learning during text comprehension. In this study, sixth graders read either a refutation or a standard text about photosynthesis. Although the text structure did not differentiate learning outcomes, participants who were able to change their misconceptions spent more time fixating previous text sentences than participants who did not revise their inaccurate prior knowledge.

1.5. Overview of the Studies

As mentioned above, the purpose of the research work carried out during my three doctorate years was twofold. The first purpose was to study how a science text accompanied by refutation statements is processed during reading, and how the processing of this type of text differs from that of a standard, non-refutation text. With this regard, all my studies are inserted in the research line recently inaugurated on the refutation text effect (Broughton et al., 2010; Kendeou & van den Broek, 2007; van den Broek & Kendeou, 2008; van den Broek, 2010). As compared to these previous studies, those included in this thesis have two added values, one methodological and the other theoretical. From the methodological point of view, the research presented here represents the first attempt to make use of the eye-tracking methodology to investigate the peculiar effect induced by a refutation text on its online cognitive processing. This, in my opinion, can be considered of interest by both educational researchers who are interested in the refutation text and its effectiveness in promoting a deeper scientific learning, and cognitive scientists who consider the study of text processing at discourse level as one of the new frontiers of reading research (e.g., Hyönä & Lorch, 2004; Rayner et al., 2006; Rayner & Slattery, 2009; Staub & Rayner, 2007; Rayner, 2009). The theoretical contribution mainly pertains to the enhanced, finer-grained level of analysis made possible by the use of eye-fixation data as indicators of text processing. Eye fixations, which can occur either during the first-pass or second-pass reading of the text (Hyönä & Lorch, 2004; Hyönä et al., 2003), indeed, offer to the researcher the opportunity of tapping into the time course of refutation text processing at discourse level. They thus permit to answer questions like: "*When* does a particular kind of processing take place during reading?". Anyway, this is not the only insight offered by eye fixations. They also allow to determine what parts of the text, for example the refutation statements or the scientific parts, are specifically involved in the processing examined. Therefore, eye fixations also permit to answer questions like: "*Where* does a particular kind of processing take place during reading?". In sum, the eye-tracking methodology enables the study of the distinct processes with different time courses that make up the refutation text effect, processes that take place on different parts of the text.

The second purpose common to the current studies was to show that different learning outcomes (offline products) of refutation text reading are related to different cognitive processes (online measures). Explicitly, that specific processes of reading predict readers' learning performance. This, in my opinion, represents quite a neglected purpose in research on text comprehension and conceptual change learning. To my knowledge, the only studies that have dealt with the relation between the readers' activities during and after text reading are a recent fMRI study carried out by Moss, Schunn, Schneider, McNamara, and vanLehn (2011) and, with respect to the refutation text, the study by Kendeou and van den Broek (2007) described in the previous sections. However, it appears to be important to provide evidence that particular patterns of reading processing as indexed by eye-fixation measures, which are prompted by the refutation nature of a text, lead to a deeper learning of the scientific concepts introduced in the text.

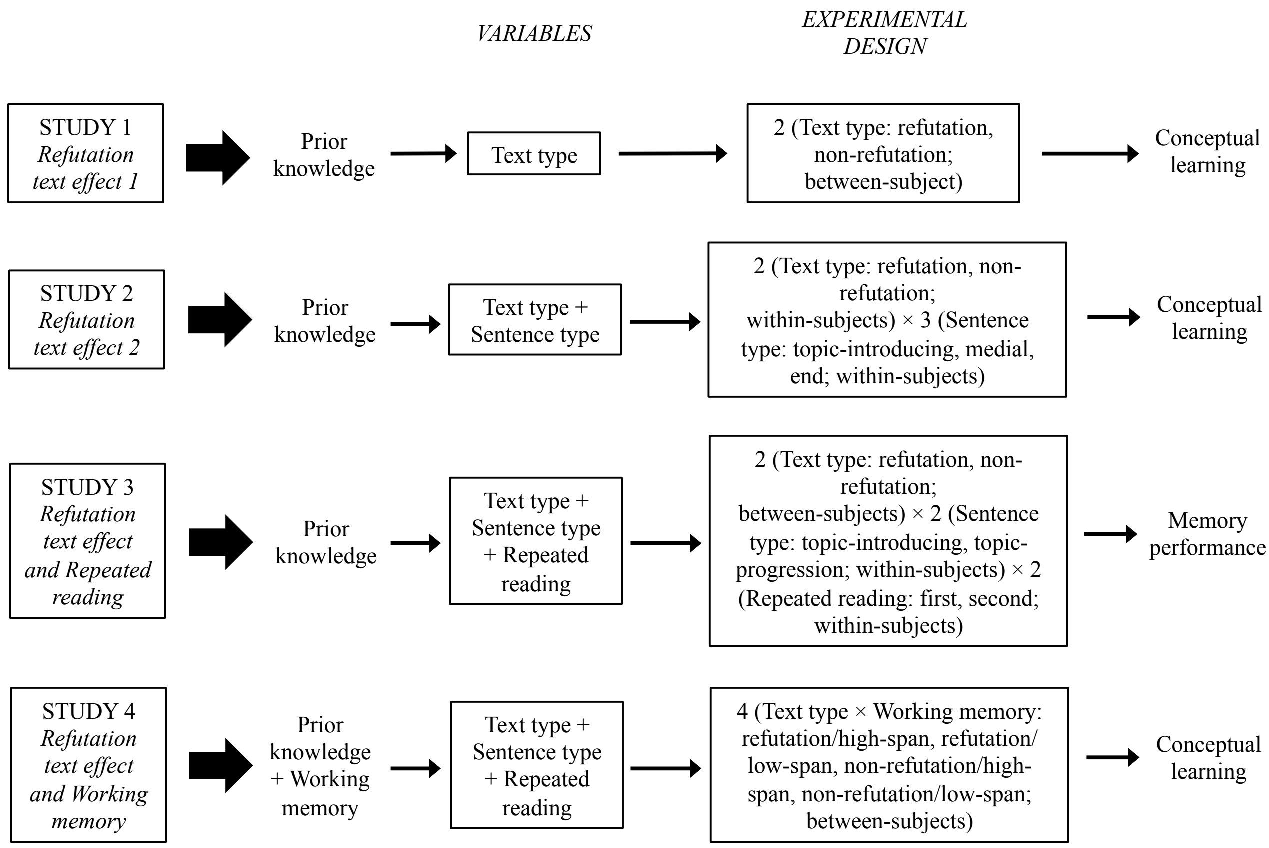
To summarize, in the three doctorate years I was able to carry out four studies. The first was a study in which the usefulness and reliability of the eye-tracking methodology was tested, and initial evidence has been collected (Study 1, Chapter 2). To go more in depth into the refutation text effect, I conducted a further experiment (Study 2, Chapter 3). This study has addressed the issue of whether the refutation text effect encompasses a series of sub-processes with different time courses (the "when" of the effect), taking place on different parts of the text (the "where" of the effect) and at different stages of reading.

The two successive studies have dealt with different purposes. The third study has investigated the relationship between the refutation text effect and text processing during repeated exposure with text information. The aim of this study was to reveal that the refutation nature of a text influences and alters the well-established (Hyönä & Niemi, 1990; Hyönä, 1995; Raney & Rayner, 1993, 1995) pattern of processing during repeated reading (Study 3, Chapter 4). Finally, the last study has focused on the readers' characteristic of verbal working memory capacity (Burton &

Daneman, 2007; Daneman & Carpenter, 1980). Specifically, it has investigated, on the one hand, whether the effectiveness of the refutation text in promoting a stronger conceptual change would be different in readers with diverse working memory capacity (low- and high-span readers); on the other hand, whether refutation text processing at discourse level would vary as a function of the readers' working memory capacity (Study 4, Chapter 5).

A graphical overview of the four studies is presented in Figure 1.1.

Figure 1.1. Overview of the four studies.



Chapter 2

First Study
Uncovering the Effects of Text Structure in Learning from a Science Text

3.1. The Study

The first study I carried out aimed to extend current research on learning from text by using eye-tracking methodology to investigate the effect of text structure on online processes of science text comprehension as well as offline learning outcomes. Specifically, we examined whether reading a refutation or a non-refutation text would induce a different type of cognitive processing, as revealed by indices of cognitive processing during reading. In addition, it was examined whether online cognitive processing, which was traced through the analysis of eye fixations, could predict offline learning outcomes. The methodology of eye tracking was implemented to measure objectively the cognitive processing during text reading without disrupting the reading task.

In this first study, a standard text was compared with a refutation one. The text topic was the phenomenon of tides, about which readers had inaccurate prior knowledge. Common misconceptions about this phenomenon include that the Moon only attracts the Earth's liquid masses, there is only one tide per day, and that the tides are caused by the attraction of the Moon only. Revision of these conceptions essentially requires applying and connecting knowledge about gravitational force, its nature and relationship with the mass and distance of heavenly objects. This knowledge, in turn, relies on further knowledge that both the Earth and Moon rotate on their own axes, and the Moon revolves with the Earth around the Sun.

2.2. Research Questions and Hypotheses

The following research questions guided the study: (1) Do readers, whose comprehension implies knowledge revision, learn better from a refutation than a non-refutation text?; (2) During the first encounter with the text, do refutation text readers process for shorter than non-refutation text readers the segments identifying the text structure (refutation vs. non-refutation statements)?; (3) Do refutation text readers process for longer than non-refutation text readers the segments presenting the scientific concepts, which are identical in both texts?; (4) Do refutation text readers differentiate from non-refutation text readers in particular for the longer returning fixation (look-back) time spent on the segments introducing the scientific concepts?; (5) Do indices of cognitive processing during text reading predict offline learning in a regression model controlling for prior knowledge and reading time?

For the first research question we hypothesized that text type would affect participants' conceptual learning, which requires knowledge revision. A replication of findings from previous research about the effectiveness of refutation texts was expected (Diakidoy et al., 2003; Mason & Gava, 2007; Mason et al., 2008; Mikkilä-Erdmann, 2002). An explanation about the underlying mechanism that makes a refutation text more powerful than a non-refutation one would come from the data regarding the cognitive processing, providing online evidence related to the impact of text type.

For the second research question, we hypothesized that since the initial encounter with the text, the refutation segments could serve as advanced organizers for the comprehension process, by triggering and speeding up the processing. The measure of fixation durations on the regions that include refutation segments should reveal that they are processed more quickly than the other parts of the text. This expectation was based on the outcome regarding reading time in the second study carried out by Kendeou and van den Broek (2007). In this study, it emerged that participants read faster the sentences providing evidence for the refutations in the refutation text than they read the control sentences in the non-refutation texts. This expectation was also consistent with the outcome of a reading-time study by Broughton et al. (2010), which showed that readers spent less time reading the refutation material.

For the third research question, we hypothesized that, overall, refutation text readers would fixate longer the segments presenting the scientific concepts, which are identical in the two texts, as revealed by the total fixation time on the corresponding regions. The refutation structure would guide readers to focus more on the parts regarding the new, accurate conceptions, as an attempt to integrate information or solve conceptual contradictions, and hence it would slow down cognitive processing. Longer cognitive processing of the scientific concepts within the refutation text may contribute to accounting for the superiority of this type of text in promoting conceptual learning through knowledge revision (van den Broek & Kendeou, 2008).

For the fourth research question, we hypothesized that refutation text readers would make, in particular, longer look-back fixations on the various sentences presenting the scientific concepts. They would concentrate more on them as this type of text activates and challenges their alternative conceptions. Co-activation of accurate and inaccurate representations, which helps recognize conceptual inconsistency (van den Broek & Kendeou 2008), would lead them to reinspect the crucial information for longer, as revealed by the duration of look-back fixations. The reinspective eye movements presumably reflect purposeful and effortful strategic behavior to resolve the perceived inconsistency (Hyönä & Nurminen, 2006).

For the fifth research question we hypothesized a clear connection between online processes and offline learning for the refutation text. It was expected that indices of cognitive processing during reading would be strong predictors of learning from this type of text since its structure supports strategic processing of the text, thus more time is spent on the critical parts of the text (Broughton et al., 2010; van den Broek & Kendeou, 2008).

2.3. Method

2.3.1. Participants

Forty (23 female and 17 male) undergraduate students of psychology (age: M = 24.4, SD = 2.11) from the University of Padova participated on a volunteer basis. They met the prior knowledge inclusion criterion by scoring 60% or lower in the measure used as pretest knowledge about the phenomenon of tides (see below), which suggests that they held alternative conceptions related to this phenomenon. All participants had normal or corrected-to-normal vision and Italian was their native language. All were competent readers. Six of these students were outliers on the posttest measure and were removed from all analyses due to scores in excess or lower than 3.0 SD from the mean. Therefore, the data of 34 students (21 female and 13 male) were considered in the statistical analyses.

2.3.2. Apparatus

Eye movements were collected by the Tobii T120 eye-tracker manufactured by Tobii Technology (Stockholm, Sweden). The eye-tracker is an infrared video-based tracking system combined with hyperacuity image processing. Tobii T120 is integrated into a 17-inch TFT monitor with a maximum resolution of 1280 × 1024 pixels. There are five near-infrared light emitting diodes (NIR-LEDs) and a high resolution camera with a charge couple device (CCD) sensor. The camera samples pupil location and pupil size at the rate of 120 Hz. Registration can be both monocular and binocular. The accuracy of eye position tracking is 0.5° and the spatial resolution is 0.2°. The Tobii T120 allows the user more freedom of head movement and greater comfort. The freedom of head movement is 30 × 22 × 30 at 70 cm and the tracker field of view is 30 × 22 × 30.

2.3.3. Texts

Two texts were prepared about the phenomenon of tides, one with a refutation structure and the other with a standard expository structure. The first was aimed at challenging the three above-mentioned common misconceptions identified among participants, that is, the Moon attracts only the waters of the Earth, there is only one tide per day, and the tides are generated by the attraction of the Moon only. The refutation text began with a refutation segment, followed by a segment introducing scientific concepts about the rotation of the Earth and Moon, and gravitational force. The third segment was also refutation, followed by a segment introducing the scientific concept that both terrestrial water and rocks are attracted. Again, the fifth segment was refutation, followed by a segment explaining the scientific concept that the phenomenon of tides occurs twice a day. The seventh segment was the last refutation part, followed by the last segment explaining that tides are caused by the attraction of both the Moon and Sun. The only difference between the refutation and standard text was that in the standard text the refutation statements were replaced by filler, non-refutation statements. The identical parts introducing the scientific concepts in the two texts were taken literally from an instructional book for high school students about physics in everyday life (Defrancesco & Oss, 2006). Figure 2.1. provides an example of the structure of the texts used.

The two texts had the same number of sentences (14), words (281), and characters (1430), as well as the same sentence and word mean lengths (when written in Italian). Each segment was of the same length and in the same position on the screen in both texts, which were prepared using the Apple Keynote ‘08 software. They were both written in Times New Roman 18 font in a text box of 954 × 735 pixels within a slide of 1024 × 768 pixels. Lines were double spaced. Both texts were presented on one screen only.

Participants were randomly assigned to the two reading groups. Eighteen participants read the standard expository text, while sixteen read the refutation text without a time limit.

Figure 2.1. Example of a concept extracted from the texts.

	Refutation statement	***Filler (Non-refutation) statement***
	Do you think that there is only one tide per day? No!	The following is some information about the number of tides per day.
Scientific segment	There are two tides a day, not only one. On one side of the Earth the waters rise because they are more strongly attracted by the Moon, while on the opposite side of the Earth the waters rise, moving away from the Earth to the opposite side of the Moon, since they are less strongly attracted by the Moon.	

2.3.4. Pre and Posttest Measures

Six multiple-choice questions were asked to measure participants' knowledge before (pretest) and after text reading (posttest), which had already been used in a pilot study. Three options were provided for answering each question: one was completely alternative (scored 0), one partly correct (scored 1), and one correct and complete (scored 2). For example, the three choices for the question "What does the Moon attract?" were: a. Only the water in the seas and oceans of the Earth. Attraction occurs during high tides (scored 0); b. Both the water and solid parts of the Earth. Attraction on water is greater because it is a fluid (scored 1); c. Both the water and solid parts of the Earth. Attraction on water is greater because it is closer to the Moon (scored 2). The three choices for the question "If the Moon is above a sea and in that sea the tide is in, what is the tide in the sea on the other side of the world?" were: a. The tide is out because the Moon can act only on the first sea (scored 1); b. The tide is out because if the water is pulled away on the other side of the world there is less water there (scored 0); c. The tide is in too but the sea on the other side of the world is less strongly attracted by the Moon (scored 2). To exemplify again, the choices for the question "What is the cause of the tides?" were: a. Gravitational force of both the Moon and Sun on the Earth (scored 2); b. Gravitational force of the closer planets on the Earth (scored 0); c. Gravitational force of the Moon on the Earth (scored 1). The lowest participant score was 2 and the highest 7. The Cronbach's alpha reliability coefficient for this series of questions was .66. It should be noted that although moderate, it is within the acceptable range as argued in the literature regarding the psychometric properties of scales developed for research purposes (Nunnally, 1978).

Participants' total scores for knowledge at pre and posttest were calculated by summing up the scores of all six questions.

2.3.5. Eye-fixation Analysis

The various text sections were defined in relation to their function: to state and refute an alternative conception or to announce the following topic, and to introduce a scientific concept. In each text there were four refutation/non-refutation statements and four segments with scientific information about the phenomenon of tides. Each text section was considered an area of interest for eye-fixation analysis. The fixation indices mentioned above were computed for each of the eight areas of interest. Specifically, three fixation indices were computed: *first-pass fixation time*, *look-back fixation time*, and *total fixation time*, which is defined as the sum of *first-pass* and *look-back fixation time*.

2.3.6. Procedure

In a department laboratory equipped with Tobii T120, participants were first asked to indicate their gender and age, and answered the prior knowledge questions. They were then given either the refutation or non-refutation text to read. After the reading task, participants completed the CAEB (Connotative Aspects of Epistemological Beliefs, Stahl & Bromme, 2007) as a distracter before measuring text comprehension. It is a semantic differential scale, comprising 17 pairs of items, which aims to capture the associative and evaluative aspects of epistemic beliefs. Participants took between 5 and 7 minutes to fill in the CAEB. Finally, participants were again asked the same initial questions as a posttest measure.

2.4. Results

A preliminary *t*-test was performed first to ensure the equivalence of the readers for prior knowledge in the two reading conditions, refutation and non-refutation text. The results showed that before the reading task, there was no statistically significant difference between the two groups, $t(32) = .91$, $p = .36$ (refutation: M = 5.81, SD = 1.75; non-refutation: M = 6.28, SD = 1.17).

2.4.1. Offline Learning

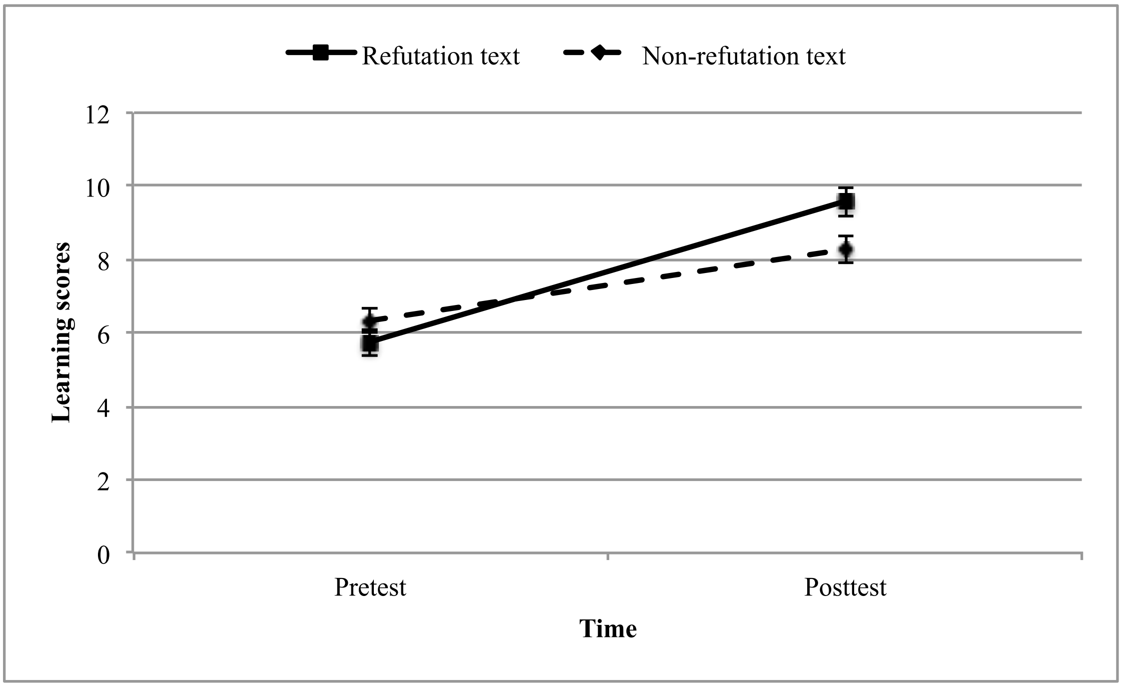
An ANCOVA for repeated measures with text type (refutation and non-refutation) as the between-subject variable), test (pretest and posttest) as the within-subject variable, and reading time as covariate, was carried out to examine knowledge gains due to text reading. It revealed the main effect of time, $F(1, 31) = 23.44$, $p < .001$, $\eta^2_p = .43$, and the interaction time × text type, $F(1, 31) = 4.67$, $p < .05$, $\eta^2_p = .13$ (Figure 2.2.). Overall, the readers of either the refutation or the standard expository texts significantly improved their conceptual knowledge about tides. However, the students who received scientific information from the refutation text were facilitated more in learning through knowledge revision, as their conceptual gains at the posttest were higher than those of standard text readers (Table 2.1.).

Table 2.1. *Adjusted Marginal Means and Standard Errors of Conceptual Learning Scores at Pre and Posttest by Text Structure.*

Text type	Pretest		Posttest	
	M	*SE*	*M*	*SE*
Refutation	5.75	0.37	9.58	0.40
Non-refutation	6.33	0.35	8.27	0.38

Note. Adjustment by covariate of reading time.

Figure 2.2. Adjusted Marginal Means of Learning Scores at Pre and Posttest by Text Structure.



2.4.2. Online Processing

A series of ANCOVAs was performed to examine the various indices of cognitive processing during text reading.

2.4.2.1. First-pass fixation time on refutation/non-refutation statements. First, we analyzed the fixation time during the first-pass reading of the refutation vs. non refutation statements of the text. An ANCOVA with text type as the independent variable and reading time and prior knowledge as covariates, revealed the significant effect of text type, $F(1, 30) = 4.81$, $p < .05$, $\eta^2_p = .14$. During the initial encounter with the text, readers of the innovative text processed for shorter the segments that challenged their current conceptions than readers of the standard text did while processing the correspondent non-refutation statements (Table 2.2.).

2.4.2.2. Total fixation time on scientific concepts. Second, we analyzed the total fixation time on the various segments that presented the scientific concepts in the texts. Another similar

ANCOVA revealed the significant effect of text type, $F(1, 30) = 5.21$, $p < .05$, $\eta^2_p = .15$. Participants who read the refutation text fixated the segments presenting the scientific concepts about tides for a longer time overall than those who read the non-refutation text (Table 2.2.).

2.4.2.3. Look-back fixation time on scientific concepts. At a more specific level, we then examined separately the fixation time on the scientific concepts during the first- and second-pass reading. No significant difference in relation to text structure emerged for the time spent on the parts presenting the scientific perspectives regarding tides during the first encounter with the text (refutation text: M = 10.41, SE = 1.11; non-refutation text (M = 11.97, SE = 1.05). In contrast, a significant effect of text type for the look-back fixation time emerged from the ANCOVA, $F(1, 30) = 4.38$, $p < .05$, $\eta^2_p = .13$. When rereading the text, the refutation text readers spent more fixation time on the four segments with scientific concepts than readers of the non-refutation text (Table 2.2.).

Table 2.2. *Adjusted Marginal Means and Standard Errors of Indices (in Seconds) of Visual Attention during Reading by Text Structure.*

Text type	First-pass Fixation Time on Refutation/Non-refutation statements		Total Fixation Time on Scientific Concepts		Look-back Fixation Time on Scientific Concepts	
	M	*SE*	*M*	*SE*	*M*	*SE*
Refutation	3.84	0.33	29.46	0.62	19.05	1.22
Non-refutation	4.86	0.31	27.50	0.58	15.47	1.15

Note. Adjustment by covariates of reading time and prior knowledge.

2.4.3. Connecting Online Processing and Offline Learning

Finally, it was examined whether cognitive processing during reading was related to learning outcomes. A hierarchical multiple regression analysis was performed for each group (refutation and non-refutation text readers) with scores for offline learning as the criterion variable. The predictors were prior knowledge and reading time in the first step, and the three examined indices of eye fixations in the second step. For the refutation text readers, the regression model for prior knowledge and reading time (first step) did not account for a significant variance of learning from text, $F(2, 13) = 3.86$, $p < .05$. The regression model for the indices of visual attention during reading in the second step, however, accounted for a significant 79% of the variance, $F(5, 10) = 7.97$, $p < .01$, with an increment of 42%. Specifically, the fixation time on the refutation segments during the first-pass reading, the total fixation time on scientific concepts, and look-back fixation time on the scientific concepts during the second-pass reading predicted learning from the refutation text. The longer the time spent processing the segments that contradict one's conceptions and the segments explaining the new scientific concepts, overall and during rereading, the greater the conceptual learning. In the second step, interestingly, reading time negatively predicted offline learning, indicating that the longer the total time spent reading the text, the lower the acquisition of new scientific knowledge (Table 2.3.).

For the non-refutation text readers, the regression model for prior knowledge and reading time (first step) accounted for a significant 65% of the variance, $F(2, 15) = 14.07$, $p < .01$. Specifically, what participants knew before text reading positively predicted what they learned from the text. The regression model for the indices of cognitive processing during reading in the second step, however, did not account for any significant increment. Although a positive relation emerged between rereading and learning, look-back fixation time did not reach statistical significance as a predictor. Learning from the non-refutation text was therefore predicted only by prior knowledge, indicating that the more accurate the readers' representations before reading the text, the greater their deep text comprehension (Table 2.3.).

Table 2.3. *Summary of Regression Analyses for Variables Predicting Learning from Text for Type of Text.*

Variable in Equation	*B*	*SE B*	*β*
	Refutation Text		
Step 1			
Reading Time	-0.01	0.09	0.29
Prior Knowledge	0.35	0.23	-0.40
R^2	0.37		
Step 2			
Reading Time	-0.25	0.05	-6.4***
Prior Knowledge	0.32	0.15	0.31
FPFT Refutation Statements	0.64	0.24	0.40*
TFT Scientific concepts	0.93	0.21	4.89**
LBFT Scientific concepts	0.21	0.07	1.28*
R^2	0.79		
Change in R^2	0.42		
	Non-refutation Text		
Step 1			
Reading Time	-0.08	0.06	-0.23
Prior Knowledge	1.04	0.22	0.73***
R^2	0.65		
Step 2			
Reading Time	0.00	0.20	-0.00
Prior Knowledge	0.92	0.23	0.64**
FPFT Non-refutation statements	0.11	0.21	0.09
TFT Scientific concepts	-0.19	0.15	-0.96
LBFT Scientific concepts	0.14	0.08	0.77
R^2	0.71		
Change in R^2	0.06		

Note. FPFT = First-pass fixation time; TFT = Total fixation time, LBFT = Look-back fixation time; * = $p < .05$; ** = $p < .01$; *** = $p < .001$.

2.5. Discussion

This study was a first attempt to extend current research on students' cognitive processing during text reading. The analysis of participants' eye fixations while reading a science text allowed to trace it. The various quantitative indices of eye fixations in the first and second encounter with the text were the online measures of cognitive processing to be related to the offline measures of learning. This relationship should provide a more complete picture of the complex phenomenon of learning from an informational text, which is the most common task in school and academic contexts.

In addition, it was considered a particular text type, the refutation, compared with a standard expository structure, for an in-depth analysis of cognitive processing stimulated by a text that aims to underline the inaccuracy of the readers' current conceptions and introduces scientific ones as viable alternatives to account for the phenomena examined. Almost all research that indicates the effectiveness of refutation texts at different educational levels, irrespective of the topic to be learned, is focused on the end products of learning from text (e.g., Guzzetti et al., 1993; Hynd, 2003). Shifting research attention to the processes underlying the learning outcomes induced by reading and the relationship between online processes and offline products are therefore paramount to drawing a more complete picture of the educational usefulness of refutation texts to promote deeper comprehension.

The first research question examined whether refutation text readers would outperform non-refutation text readers at the posttest, showing greater restructuring of their alternative conceptions as revealed in the pretest. As hypothesized and in line with most previous studies (e.g., Alvermann & Hynd, 1989; Diakidoy et al., 2003; Mason et al., 2008), the refutation text used in this study induced a deeper comprehension than the standard text.

To understand the cognitive processing which takes place during text reading, the second research question asked whether the refutation text segments would be fixated for a shorter time than the corresponding control segments. The hypothesis was confirmed since shorter processing time was devoted to the manipulated text segments during the first-pass reading by the refutation text readers. The explanation for this finding is that processing speed is influenced since the refutation text activates the relevant prior knowledge, which is incorrect. As a result, refutation information is processed faster than in the case of the non-refutation text segments.

The third research question asked whether the refutation text readers would allocate more attention overall to the various segments presenting the new scientific concepts, which were identical in both texts. Findings again confirmed the hypothesis, as the information to be learned, which conflicted with the readers' alternative conceptions, was fixated longer by the refutation text readers. This outcome is also consistent with van den Broek and Kendeou's (2008) research findings on reading time. The co-activation of alternative and scientific conceptions about tides probably helped the refutation text readers to perceive a conceptual inconsistency, hence their cognitive processing slowed down. Co-activation accounts for why a refutation text, more than a standard expository text, can augment readers' metaconceptual awareness of their own, which has been theorized by conceptual change scholars (Mason & Gava, 2007; Vosniadou, 2003).

The fourth research question asked at a more specific level whether the look-back fixation time on the scientific concepts would be longer on the refutation than the non-refutation text. As expected, the look-back fixation time was longer on the former. Cognitive processing during look-back fixations on crucial information presumably indicates a strategic and purposeful behavior of readers who recognize a conceptual inconsistency and intend to resolve it (Hyönä & Nurminen, 2006).

Considered collectively, the findings about the three measures of cognitive processing during reading indicate that on the one hand, the refutation text assists readers to activate their current conceptions during the initial processing of the material since the refutation segments, which precede the scientific concepts, are fixated faster. On the other hand, this type of text made readers slow down their cognitive processing when reading the segment presenting the scientific concepts, especially during the second-pass reading. This suggests that a conceptual conflict may be perceived (van den Broek & Kendeou 2008), requiring an intentional cognitive effort to be resolved (Sinatra & Pintrich, 2003).

Finally, the connection between online and offline measures of text reading was examined in the fifth research question, which asked whether the three indices of eye fixations predicted offline learning. The hypothesis was confirmed. For the non-refutation text only prior knowledge predicted learning. In contrast, for the refutation text readers, the examined indices of visual attention during reading predicted learning from text. In addition, reading time was a negative predictor. Considering together all the predictors of learning from the refutation text, it can be said that better learning is positively related to strategic reading, which does not imply longer reading but a longer focus on the essential segments. The quality, not the quantity, of reading is entailed in deep text comprehension, that is, it is crucial how the reading time is spent. This finding confirms the strategic reading traced in two eye-tracking studies carried out by Hyönä and associates (Hyönä et al., 2002; Hyönä & Nurminen, 2006), which revealed that a group of readers, defined as topic structure processors, who were able to focus on topic sentences of an expository text, selectively looked back to pertinent regions and wrote the more comprehensive text summaries.

In addition, findings show that the refutation text supports and drives readers' attention, pointing out the role played by a strategic rereading of scientific concepts.

In conclusion, evidence that text type (refutation vs. non-refutation) influences cognitive processing of the different segments within it has been provided. In particular, this first study offered new insights about why readers of a refutation text achieve the highest scores in offline measures of text comprehension. The study also documented the important connection between online cognitive processes and offline measures of learning from text in the interplay of readers' prior knowledge and text type. Therefore, the first study extended current research on the refutation text and contributed to further develop a new field of study (Mikkilä-Erdmann et al., 2008), whose the analyses of cognitive processes during refutation text reading constitutes the core.

Chapter 3

Second Study
The Refutation Text Effect: "When" and "Where" It Occurs during Reading

3.1. The Study

In the second study, we investigated the issue, still open at the end of the first study, of whether the refutation text effect encompasses a series of sub-processes with different time courses, which take place on different parts of the text and at different stages of reading. Along with the processing of refutation statements, the processing of topic-introducing sentences was of particular interest. Information from two texts about the phenomena of tides and Darwinian natural selection was either introduced by refutation or non-refutation statements, which are sentences that only anticipated the text content. Information was arranged in four subtopics, each including a topic-introducing sentence followed by sentences that elaborated on the information provided in the topic-introducing sentence (medial sentences) and an end sentence that summarize and wrap up the concepts presented in the topic-introducing and medial sentences. Students' prior knowledge about the topics was first assessed by means of open-ended questions. Then, the students read both the refutation and non-refutation text for each topic. Students' comprehension of each topic was then evaluated at the end of the reading of the corresponding text.

3.2. Research Questions and Hypotheses

Documented the superiority of refutation text in promoting a better conceptual learning, the following questions guided the study: Are readers facilitated while processing a refutation text?

(1a); Which is the time course of this hypotized facilitation effect (1b)? What parts of the text are concerned with such a facilitation (1c)?; Are readers actually more strategic during the reading of a refutation text (2a)? Which is the time course of the hypotized strategic behavior during the reading of the refutation text (2b)? What parts of the text are concerned with it (2c)? The hypotheses that directly rose up from those research questions were the following: refutation text would require less cognitive resources, to be comprehended, therefore its readers would be facilitated (1a); this facilitation would take place during the initial processing of refutation text reading and would be reflected in shorter first-pass fixations (1b). This effect would be observed on the topic-introducing sentences within the text (1c). Readers would be more strategic while processing the refutation text (2a); this strategic behavior would be revealed by the longer look-back fixations (second-pass reading) (2b) on the refutation parts while reading the text segments introducing the scientific conceptions as compared to the duration of look-backs to the non-refutation parts (2c).

Thus, there were two main research questions, the first and second. The former asked for the facilitation effect during refutation text reading whereas the latter was about the strategic behavior while reading a refutation text. At a more fine-grained level, the “when” and “where” of both these processes were investigated, asking for what parts of the text they take place and at what stage of reading processing.

3.3. Method

3.3.1. Participants

Forty (25 female) students from a large public university in northeastern Italy took part in the experiment on a voluntary basis. Their mean age was 25.1 years (SD = 4.7). They met the prior knowledge inclusion criterion by scoring 60% or lower in the measure used as pretest knowledge about the phenomenon of tides and Darwinian natural selection (see below), which suggests that they held alternative conceptions about these topics. All the participants were Caucasian, native speakers of Italian, and had normal or corrected-to-normal vision. All were competent readers. Three participants had to be excluded due to poor calibration.

3.3.2. Apparatus

Eye movements were collected using the Tobii T120 eye-tracker, manufactured by Tobii Technology (Stockholm, Sweden), which was already used in the first study (see Chapter 2).

3.3.3. Texts

Two texts, adapted from previous studies were used: a text introduced information about the phenomenon of tides and the other was about the Darwinian natural selection. For each text, refutation and non-refutation versions were prepared. Thus, a total of four texts were used. All texts had an identical structure. They were divided into five pages. The first page of the text about tides presented basic information about the rotation of the Earth and Moon, and Newton's law of universal gravitation, whereas the first page of the text about natural selection presented a description of Darwin's travels and observations around the world that inspired his understanding of the natural selection.

The first page was identical in both the refutation and non-refutation versions of each text. The pages from the second to the fifth introduced four distinct concepts. The four concepts included in the text about the phenomenon of tides were: (1) The force of gravitational attraction from the Moon attracts both the terrestrial waters and rocks; (2) the phenomenon of high tide occurs twice a day; (3) the tides are caused by the joint forces of gravitational attraction from the Moon and Sun; (4) The force of gravitational attraction from the Moon is influent only because it acts on enormous masses of waters like the terrestrial oceans.

The four subtopics included in the text about Darwinian natural selection were: (1) not all the animals within the same species are identical; (2) within a species, the number of animals generated is higher than the number of animals that become adults; (3) the animals that casually have characteristics fitting a particular environment are the only survivors; (4) throughout generations, a lot of mutations take place that lead to the development of new species.

The four concepts were presented in separated paragraphs of text, each presented in a different page. Each paragraph contained three sentence types, a topic-introducing sentence, several sentences that elaborated on the information provided by the topic-introducing one (medial sentences), and an end sentence (Hyönä, 1995; Hyönä & Lorch, 2004; Lorch, Lorch, & Matthews, 1985). The four concepts presented in the pages from the second to the fifth were identical in the two text versions of each text but were introduced by either refutation or non-refutation statements.

Examples of one of the refutation statement and its corresponding non-refutation statement in the text about the phenomenon of tides are: “Are you convinced that the phenomenon of high tide takes place only once a day? Certainly not!” (refutation); “The following is some information about the number of high tides that take place in a day” (non-refutation). An additional example, from the text about Darwinian natural selection is: “Do you think that all the animals of a species are exactly identical and fit the environment? No, it is not like this!” (refutation); “The following is some information about the animals of a species and their descent” (non-refutation). Figure 3.1. provides an example of the structure that was common to all the texts used.

The refutation version of the text about tides was 659 words in length (the refutation statements comprised of 68 words) whereas the non-refutation version had 641 words (the non-refutation statements comprised of 50 words). The part shared by the two versions of the text was 591 words in length. In contrast, the refutation version of the text about Darwinian natural selection was 663 words in length (the refutation statements comprised of 91 words) whereas the non-refutation version had 639 words (the non-refutation statements comprised of 67 words). The part shared by the two versions of the text was 572 words in length. All text versions were displayed in the Courier New 14 black font on a white background, and presented double-spaced on the screen. The first page of all text versions included 7 lines. In all text versions, the pages from the second to the fifth comprised 6 to 12 lines.

Figure 3.1. Example of a concept extracted from one of the texts (phenomenon of tides).

	Refutation statement	***Filler (Non-refutation) statement***
	Are you convinced that the phenomenon of high tide takes place only once a day? Certainly not!	The following is some information about the number of high tides that take place in a day.
Topic-introducing sentence	The phenomenon of high tide takes place twice a day, not only once.	
Medial sentences	The Moon attracts the waters that are relatively close to it but its attraction can not affect the waters (that is, the oceans) that are on the opposite side of the Earth. These fluid masses are at a larger distance from the Moon, not only than the waters that the Moon is attracting in a particular moment but also than the mass of the Earth (better, than its centre). Since they are more far, these waters are less strongly attracted by the Moon and can grow away from the Earth to the opposite side of the Moon. In other words, on one side of the Earth, that in front of the Moon, the waters rise up since the Moon attracts them strongly; at the same time, on the other side of the Earth the waters rise up, growing away from the Earth to the opposite direction from where the Moon is, due to the weak attraction the latter exerts on them.	
End sentence	The result is: two "bulges" a day, that is, the double high tide.	

3.3.4. Procedure

Before starting the actual experiment, participants were asked to answer four prior-knowledge questions about each topic. Following, the eye-tracker was calibrated for each participant. Participants were then told that they would read a text about tides or evolution, and they were instructed to read the text for comprehension, imagining it was included in a textbook they had to study for an exam. They were also instructed to switch from the first to the subsequent pages of the text by pressing the spacebar on the computer keyboard.

Participants were then given either the refutation or the non-refutation version of the text. Reading was self-paced with the restriction that returning to previous pages was prevented. At the end of the first reading, participants were asked to answer again the questions about the topic they had just read in the text. These questions served as comprehension test questions. Following, the eye-tracker was recalibrated. Participants were then given the other version (refutation or non-refutation) of the text introducing information about the other topic. At the end of the second reading, participants were asked to answer again the questions about the topic they found in the last text read. The entire experimental session lasted approximately 45-50 minutes.

3.3.5. Dependent Variables

3.3.5.1. Eye-fixation measures. Three eye-fixation measures, computed for each of the target text sentences (topic-introducing, medial, and end sentences, and refutation vs. non-refutation statements), served as dependent variables: (1) *first-pass progressive fixation time* (forward fixations), (2) *first-pass reinspection time* (reinspective fixations), and (3) *look-back fixation time* (look-back fixations).

All these eye-fixation measures were converted to time-per-character measures in order to control for the differences in length among the diverse sentence types.

3.3.5.2. Pre and Posttest Measures. Participants' knowledge at pre and posttest was measured by eight questions: four open-ended questions about the phenomenon of tides (Cronbach's α = .72 at pretest and .79 at posttest) and four open-ended questions about the Darwinian natural selection (Cronbach's α = .80 at pretest and .74 at posttest). The four open-ended questions about the phenomenon of tides were: 1. "What parts of the Earth are affected by the tidal force? Explain your answer"; 2. "How many times per day does the high tide take place? Explain your answer?"; 3. "If you should indicate the cause of the phenomenon of tides, what would you write? Explain your answer"; 4. "What do you think about the influence of the celestial bodies on the Earth? Explain your answer?". The four open-ended questions about the Darwinian natural selection were: 1. "From the genetics point of view, "how" are the animals of a species? Explain your answer."; 2. "In each generation, which is the ratio between the animals that born and those that become adults? Explain your answer"; 3. "If you should indicate what is the role played by the environment in determining the change of the animals, what would you write? Explain your answer"; 4. "What do you think about the origin of new species? Explain your answer". Two independent raters coded the answers to these open-ended questions. They scored a completely alternative answer 0, a partly correct answer 1, and a correct and complete answer 2. As revealed by Cohen's *k*, inter-rater reliability ranged from .89 to .91 at the pretest and from .88 to .93 at the posttest for the questions about the phenomenon of tides, and from .94 to .98 at the pretest and from .87 to .90 at the posttest for the questions about the Darwinian natural selection. Disagreements were resolved through discussion.

Participants' total scores for knowledge at pre and posttest were calculated by summing up the scores of all four questions, separated for the topics of the phenomenon of tides and Darwinian natural selection.

3.3.6. Data Analyses

Eye-fixation data were analyzed by means of mixed-effect multiple regression models in R (Baayen, 2011; Bates, Maechler, & Bolker, 2011; R Development Core Team, 2011). Mixed-effect models are statistical models that incorporate both fixed-effect and random-effect terms (Baayen, 2008; Pinheiro & Bates, 2000). This kind of model is appropriate for the analysis of sentence-level eye fixation times since expository texts are organized hierarchically. In fact, sentences (e.g., topic-introducing and end sentences) belong to paragraphs (e.g., concepts), which in turn occur in specific texts (e.g., refutation and non-refutation); these texts are then read by different participants (Richter, 2006). This results in different sources of variance that need to be taken into account. With the exception of a few studies (e.g., Kuperman, Schreuder, Bertram, & Baayen, 2009), previous investigations examining eye fixations at word- and sentence-level have underestimated this fact, thus seriously threatening the statistical validity of their conclusions (Baayen, 2008).

Separate models were fitted for the text structure (topic, medial, and end sentences), and for the refutation vs. non-refutation statements. Each model had one of the three eye-fixation measures as the dependent variable. The models for the text's topic structure included a random effect for participant, and text type (refutation and non-refutation; within-subject) and sentence type (topic-introducing, medial, and end; within-subjects) as fixed effect factors. On the other hand, the models for the refutation vs. non-refutation statements comprised a random effect for participant and only the text type (refutation, non-refutation; within-subjects) as fixed effect factor. In the models, all fixed effect factors (text type and sentence type) were contrast coded: the non-refutation text served as baseline for comparison with the refutation text and the end sentences served as baseline for comparison with the topic-introducing sentences and medial sentences.

Before fitting the models, the outliers on each eye-fixation measure were identified (i.e., values that fell beyond 3.0 SD from the mean). These outliers were removed from the respective datasets (one for each fitted model) and thus excluded from the statistical analyses, to avoid distortions of the model estimates due to extreme observations. The mean percentage of removed eye-fixation times (averaged across the datasets) was 0.9% (range: 0-2.2%).

3.4. Results

The results section is outlined as follows: first, preliminary analyses as well as results regarding the offline products of learning from the refutation vs. non-refutation text are introduced. Following, findings from the models for the processing of the text's topic structure, including topic-introducing, medial, and end sentences, are presented. Finally, results from the models for the processing of refutation vs. non-refutation statements are reported.

As described above (see the Method, Data Analyses subsections), the non-refutation text for the fixed effect of text type and the end sentence for the fixed effect of sentence type were used as the baseline. Thus, the values and signs of the estimates of the fixed effects reported below reflect the effects of the refutation text and the topic-introducing and medial sentences as compared to their respective baselines.

3.4.1. Preliminary Analyses

An ANOVA with text type (refutation and non-refutation; within-subjects) and topic (tides, Darwinian natural selection; within-subjects) as independent variables was performed first to ensure the equivalence of the groups for prior knowledge. It showed no statistically significant difference (all *p*s > .10). Thus, prior knowledge was not considered as a covariate in the following analyses.

3.4.2. Offline Products

Results from a 2 (text type: refutation, non-refutation) × 2 (text topic: tides, natural selection) within-subjects ANOVA revealed that readers learned more from the refutation (M = 5.83, SE = .23) than the non-refutation text (M = 4.35, SE = .28), $F(1, 69) = 5.92$, $p = .018$, $n^2_p = .18$. The main effect of topic and the interaction between text type and topic did not result in significant effects (both *p*s > .10).

Since the topic of the text as well as the interaction between text topic and text type did not impact on readers' learning performance, these predictors were not included in the models of online processing during reading.

Table 3.1. *Means of Each Eye-Fixation Measure (in Milliseconds-per-Character) by Text Type and Sentence Type (Standard Deviations in Parentheses).*

	Topic-Introducing Sentences		Medial Sentences		End Sentences	
	R	NR	R	NR	R	NR
First-pass Progressive Fixation Time	13.19	15.33	3.19	4.57	14.89	13.46
	(10.93)	(12.27)	(3.20)	(4.21)	(9.00)	(9.22)
First-pass Reinspection Time	7.34	11.48	25.64	24.57	15.03	12.61
	(10.30)	(13.26)	(20.11)	(19.65)	(14.96)	(13.35)
Look-back Fixation Time	36.57	40.15	27.25	28.82	16.33	19.82
	(31.14)	(37.32)	(23.07)	(25.87)	(20.62)	(24.07)

Note. R = Refutation text; NR = Non-refutation text.

3.4.3. Processing the Text's Topic Structure

The means and standard deviations for all eye-fixation measures are presented in Table 3.1.

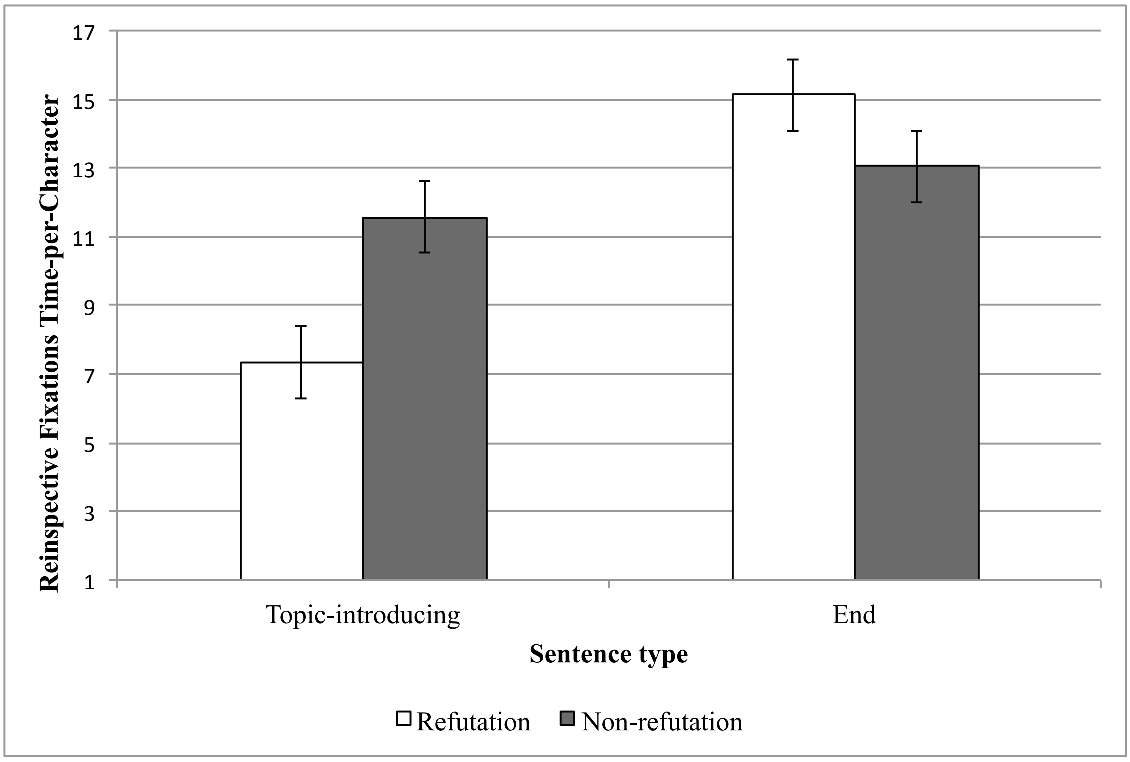
3.4.3.1. First-pass progressive fixation time. The results from the model for the first-pass progressive fixation time showed the significant main effect of topic-introducing sentences, estimate = 3.44, t = 8.71, p = .0001, and that of medial sentences, estimate = -6.84, t = -17.26, p = .0001. First-pass progressive fixation time on topic-introducing sentences was longer than that on end sentences. Moreover, forward fixations on medial sentences were shorter than forward fixations on end sentences. The main effect of text type as well as the two-way interaction between text type and sentence type did not reach significance (p > .10).

The full specifications of the fixed and random effects of the model for the first-pass progressive fixation time are reported in Table A1 and Table A4, respectively (see Appendix A).

3.4.3.2. First-pass reinspection time. Regarding the first-pass reinspection time, findings from the model revealed the significant main effect of topic-introducing sentences, estimate = -6.79, t = -11.09, *p* = .0001, and medial sentences, estimate = 8.94, *t* = 13.23, *p* = .0001. Longer first-pass reinspection time was spent when reading end sentences than topic-introducing sentences. Moreover, reinspective fixations on medial sentences were longer than those on end sentences. In addition, the interaction between text type and sentence type proved significant, estimate = -1.95, *t* = -2.88, *p* = .005 (Figure 3.2.). Readers spent shorter first-pass reinspections on the topic-introducing sentences in the refutation text than on topic-introducing sentences in the non-refutation text; in contrast, the summed duration of first-pass reinspections devoted to the end sentences was longer during refutation text reading than while reading the standard, non-refutation text.

The full specifications of the fixed and random effects of the model for the first-pass reinspection time are reported in Table A2 and Table A4, respectively (see Appendix A).

Figure 3.2. Estimated Means (and Standard Errors) of First-pass Reinspection Time by Text Type and Sentence Type.



3.4.3.3. Look-back fixation time. The results from the model for the look-back fixation time showed the significant main effect of topic-introducing sentences, estimate = 10.23, $t = 8.39$, $p = .0001$. Look-back fixation time on topic-introducing sentences was longer than that on end sentences. The main effect of text type as well as the two-way interaction between text type and sentence type did not reach significance ($p > .10$).

The full specifications of the fixed and random effects of the model for the look-back fixation time are reported in Table A3 and Table A4, respectively (see Appendix A).

3.4.4. Processing the Refutation vs. Non-refutation Statements

The means and standard deviations for all eye-fixation measures are presented in Table 3.2.

Table 3.2. *Means of Eye-Fixation Measures (in Milliseconds-per-Character) by Text Type (Standard Deviations in Parentheses).*

	Refutation Text	Non-refutation Text
First-pass Progressive Fixation Time	18.27 (12.50)	17.67 (9.92)
First-pass Reinspection Time	6.89 (9.31)	5.57 (6.39)
Look-back Fixation Time	23.00 (22.86)	16.66 (18.34)

3.4.4.1. First-pass progressive fixation time. The effect of text type was not significant ($p > .10$).

3.4.4.2. First-pass reinspection time. The effect of text type was not significant ($p > .10$).

3.4.4.3. Look-back fixation time. The model for the look-back fixation time showed that the effect of text type proved significant, estimate = 3.09, $t = 2.68$, $p = .010$. Readers made longer look-backs on the refutation statements than on the corresponding non-refutation statements in the standard text.

It should be noticed that, apart from the refutation or non-refutation statements in the standard text, in each page of the texts only the scientific parts were present. Thus, look-back fixations on the former statements necessarily came from the scientific parts (look-froms).

The full specifications of the fixed and random effects of the model for the look-back time are reported in Table A5 and Table A6, respectively (see Appendix A).

3.5. Discussion

The aim of this study was to go more in depth into the refutation text effect, to further clarify what emerged in the previous investigation (see Chapter 2). Specifically, it was investigated if the refutation text effect embeds distinct sub-processes with different time courses, which take place on different parts of the text. Two were the sentence types we were particularly interested in unveiling the online processing during reading: the refutation statements (Guzzetti, 2000; Maria & MacGinitie, 1987) and the topic-introducing sentences, which have been proved to be particularly important within the topic structure of the text (Hyönä, 1995; Hyönä & Lorch, 2004).

Documented, once more, the well-known superiority of refutation text in promoting a better conceptual learning (e.g., Broughton et al., 2010; Diakidoy et al., 2003; Mason et al., 2008; Kendeou & van den Broek, 2007; van den Broek & Kendeou, 2008), two main research questions inspired the study, each including three subquestions. The first research questions (1a, b, and c) asked whether a facilitation effect would actually take place during refutation text reading, as well as the “when” and “where” of this effect. The second research questions (2a, b, and c) asked whether the refutation text would prompt the use of strategies while reading and the “when” and “where” of these strategies.

Findings from the models for the text's topic structure confirmed all the hypotheses about the facilitation effect during refutation text reading. Readers spent shorter first-pass reinspections on the topic-introducing sentences in the refutation text than on the topic-introducing sentences in the non-refutation text. These results showed that the refutation text produces facilitation during initial text processing, particularly during the first-pass reinspective fixations. Interestingly, this facilitation effect did not regard the whole text, but was exclusive of the sentences that introduce new topics in the text (topic-introducing sentences). Apart from the documented prominent role they play within the text's topic structure (Hyönä, 1995; Hyönä & Lorch, 2004), the latter were also the sentences closer to the refutation statement (in the refutation text). Thus, the effect of the refutation statements during the initial construction of text representation was increased while reading the topic-introducing sentences. This resulted in facilitation during early comprehension - not linguistic - processes, which are captured by reinspective fixations. In this respect, it is arguable that refutation statements acted as advanced organizers of text processing (Kendeou & van den Broek, 2007; van den Broek & Kendeou, 2008), providing the readers with a plan to retrieve from memory relevant knowledge associated with the text information. By providing a peculiar species of retrieval cues (Ericsson & Kintsch, 1995) to readers, refutation statements supported them in retrieving their alternative ideas from memory. This made the subsequent processing of the scientific explanations, the essential of which was introduced in the topic-introducing sentences within each subtopic, less difficult to carry out.

Along with the cognitive interpretation of the facilitation effect found at first-pass reading (reinspective fixations) of the refutation text, an additional, "warm" interpretation can be plausible in the light of Broughton and colleagues' (2010) findings. These authors monitored the first-pass reading of a refutation text about seasonal change by measuring readers' sentence-by-sentence reading times. Their findings showed that the refutation segment was read significantly faster than the corresponding sentences in the standard text. Their interpretation was that faster reading times while reading the refutation segment are determined by the fact that readers find the refutation segment particularly interesting (Lehman, Schraw, McCrudden, & Hartley, 2007). In other words, it is possible that refutation statements, highlighting the inconsistencies between readers' prior conceptions and text information, make text information more interesting to attend. With respect to the results of the present study, it is plausible that refutation statements stimulated text-based interest in learning new information about the topics introduced. This higher interest, in turn, facilitated the early text processing and representation.

Although it was not explicitly predicted, the results from the visual behavior of readers at first-pass reading revealed a further, interesting cognitive phenomenon, which involved the processing of end sentences within the refutation text. Precisely, the summed duration of first-pass reinspections devoted to the end sentences was longer during refutation text reading than while reading the standard, non-refutation text. This could be interpreted by claiming that after "scrolling down" the refutation text during the first encounter with it, the readers reinvested the cognitive resources saved during the reading of the topic-introducing sentences. The end sentences served as the tool of this operation, given that the stronger integration took place during the reinspective fixations on the end sentences. This suggests that the refutation text also prompts the execution of peculiar "wrap-up" processes, that is processes the readers execute to extract the global meaning of a text sentence (Rayner, Kambe, & Duffy, 2000). Several studies (e.g., Just & Carpenter, 1980; Rayner et al., 2000; Rayner, Sereno, Morris, Schmauder, & Clifton, 1989), have documented that fixation durations on a word are inflated when the word ends a clause or sentence. Since the sentences in these studies were identical except for their location within the text, it is largely agreed upon the fact that this extra fixation time is due to integrative processing that takes place at clause and sentence boundaries (Staub & Rayner, 2007). In the present study, the end sentences of each subtopic were identical across the two text types (refutation and non-refutation) but significantly longer processing time was devoted to end sentences in the refutation text. The conclusion is, thus, twofold: first, wrap-up processes may be of comprehension nature - not only linguistic phenomena - and take place at discourse level; second, these processes may be prompted by a text type that actively organizes the processing during reading (Kendeou & van den Broek, 2007) and allows to save resources during comprehension, as the refutation text does.

For what concerns the three hypotheses about the strategic processing during refutation text reading, they were confirmed by findings from the model for look-back fixation time on the refutation vs. non-refutation statements. Readers made longer look-backs on the refutation statements than on the corresponding non-refutation statements in the standard text. It should be noticed that, apart from the refutation or non-refutation statements in the standard text, in each page of the texts only the scientific parts were present. Thus, look-back fixations on the former statements necessarily came from the scientific parts and corresponded to look-from sequences from the topic-introducing, medial, or end sentences to the refutation or non-refutation statements.

The findings reported above are important since they clarify the peculiar nature of the processing that occurs during the second-pass reading of the refutation text. Not all the look-backs were longer during refutation text reading as compared to those made on the non-refutation text, but only a specific subclass of them identified by the look-backs launched while reading the scientific parts and selectively directed to the refutation statements. Two studies by Hyönä and associates (Hyönä, Lorch, & Kaakinen, 2002; Hyönä & Nurminen, 2006) appear useful to shed light on the cognitive nature of this kind of look-backs.

Hyönä and colleagues (2002) identified different reading patterns on the basis of eye movements. Two of the identified reader profiles were characterized by longer look-back fixations: the non-selective reviewers and topic structure processors. Non-selective reviewers looked back extensively but not selectively during reading; in contrast, topic structure processors specifically backtracked the parts of the text that introduced the most relevant information. In a following investigation, Hyönä and Nurminen (2006) observed that look-backs to the most important segments of the text made by topic structure processors are strategic in nature. Noteworthy, the texts used in these two studies (Hyönä et al., 2002; Hyönä & Nurminen, 2006) used headings as signaling devices to signal important information within text (Lorch, 1989; Lorch & Lorch, 1996).

A distinctive feature of topic structure processors, qualifying them as strategic readers, was that they backtracked the headings for longer time than the other readers' groups. Hence, signaling served as the primary prompt for strategic behavior during reading.

With respect to the look-back behavior of the readers in the present study, the presence of the refutation statements prompted the use of strategies during reading. While reading the refutation text, readers behaved as the topic-structure processors did in Hyönä and colleagues' studies (Hyönä et al., 2002; Hyönä & Nurminen, 2006): they looked back intensively the refutation statements while processing the new information, and were then able to better comprehend the scientific concepts introduced in the text, as revealed in the analyses about the offline products of learning. On the basis of the evidence from previous studies regarding the second-pass reading, look-back fixations can be assumed as an indicator of strategic processing. Thus, readers are more strategic while processing the information during refutation text reading.

To summarize, this study added to the previous research (see Chapter 2) by providing objective evidence that the refutation text effect is not a unique effect. Rather, it represents a composite effect of sub-processes that take place in different parts of the text (the "where" of the effect) and at different stages over the time course of reading (the "when" of the effect). The milestones of the refutation text effect as emerged from the present study can be synthesized in the following way, arranged on the basis of "when" they occur during refutation text processing (from the earlier processes to the more delayed):

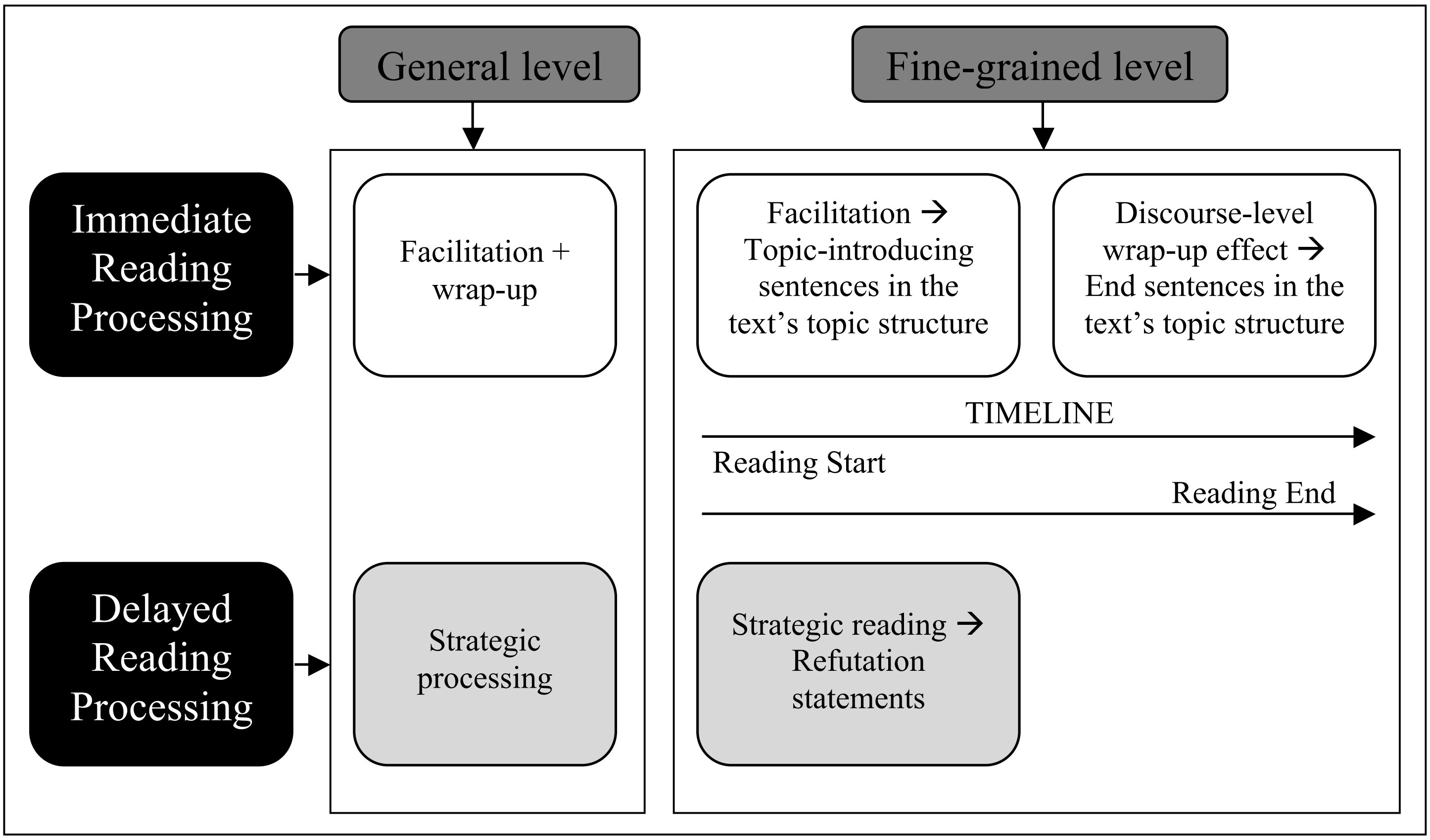
(1) The refutation text produced a facilitation effect. This facilitation effect takes place during first-pass reinspective fixations and regards the sentences that introduce new topics in the text (topic-introducing sentences).

(2) The refutation text prompts the execution of wrap-up processes at discourse level, that is, it supports the readers to extract the gist of a text segment. These wrap-up processes occur during first-pass reinspective fixations on the end sentences.

(3) The refutation text makes the readers more strategic while processing the information during reading. This represents a delayed effect, taking place during look-back fixations, and regards the refutation statements while reading the scientific parts.

A graphical representation of the distinct cognitive sub-processes composing the refutation text effect is presented in Figure 3.3.

Figure 3.3. The "When" and "Where" of the Refutation Text Effect.



Chapter 4

Third Study
The Strategic Nature of Refutation Text Processing during Repeated Reading

4.1. The Study

In the third study, we integrated research on text processing during repeated reading (Hyöna & Niemi, 1990; Raney & Rayner, 1993) with research on the refutation text effect. Information from an expository text about the phenomenon of tides (see Chapter 2) was either introduced by refutation statements or by sentences that only anticipated the text content (filler sentences). Information was arranged in three subtopics, each including a topic-introducing sentence followed by several sentences that elaborated on the information provided in the topic-introducing sentence (topic-progression sentences, Hyönä, 1995). In the initial reading, half of the participants read the refutation version of the text and half the non-refutation version. Following, participants reread the text without refutation or filler statements. Hence, in the second reading all participants read the same text.

4.2. Research Questions and Hypotheses

The main research question that guided our study was: (1) How do readers make use of refutation signals during repeated reading of text? There are three possibilities. The first prediction is that refutation texts trigger strategic processing during rereading (1a). In other words, we expect increased strategic reading of important parts of text during rereading, namely, increased look-backs to parts of text that introduce the scientific explanation. This prediction is supported by the findings, presented in the first study (see first study, Chapter 2), showing that the look-backs of refutation text readers to the text segments presenting the scientific explanations were longer than those of non-refutation text readers, thus describing the former as more strategic. This hypothesis is in line with the context-dependent representation model for explaining text repetition effects (Raney, 2003), which states that if the textbase is reinstated in the context of different situation models there is little to no repetition benefit. As a matter of fact, the discrepancy between the situation models in the first and second reading is larger for refutation text readers, whose situation model from the initial reading comprises both the scientific explanations and the misconceptions. Consequently, during rereading refutation text readers could reinstate the context provided by the refutation statements just read, and this would result in a loss of repetition benefit (e.g. Hyönä & Niemi, 1990; Raney & Rayner, 1993), that is, a repetition cost.

The second prediction concerns the effects that the refutation statements have on the processing of the different components of the text structure across repeated reading. Topic-introducing sentences, which are the most important sentences within the text hierarchy, have been documented to receive extra processing time as compared to topic-progression (medial and end) sentences (Hyönä, 1995; Hyönä & Lorch, 2004). In addition, rereading benefits have been shown to be greater in magnitude for topic-introducing sentences than for other sentences (Hyönä, 1995). We hypothesized that refutation text would speed up the processing of topic-introducing sentences as compared to the non-refutation text (1b). Previous research has showed that signals such as headings facilitate the reading of topic-introducing sentences (Hyönä & Lorch, 2004), and that reading of topic sentences is also facilitated if the information introduced by topic-introducing sentences can be directly related to immediately preceding sentences (Lorch, Lorch, Gretter, & Horn, 1987; Vauras, Hyönä, & Niemi, 1992). Furthermore, the refutation statements would amplify the importance of the information contained in the topic-introducing sentences, making them more interesting to read (Broughton et al., 2010).

However, it is also possible that refutation text reduces the need to backtrack in the text as compared to the non-refutation text. If refutation text readers construct a good understanding of the text information during the initial reading, they do not need to invest extra effort to comprehend the important text information during rereading. Thus, a general facilitatory effect of rereading for refutation text is also possible (1c).

In addition to the main research question concerning refutation text processing during repeated reading, another question was: (2) is it possible to predict readers' memory performance on the basis of the online processing during reading? To answer this question, we hypothesized different effects for the refutation and non-refutation text readers. For the readers of the refutation text, a stronger strategic behavior during reading would predict comprehension performance (2a). Previous results (see Chapter 2) has documented that learning outcomes of refutation text readers who look back for longer the information and co-activate more the scientific explanations and inaccurate ideas (Kendeou & van den Broek, 2007; van den Broek & Kendeou, 2008) are enhanced. For the readers of the non-refutation text, no study has found that a particular pattern of processing predicts their comprehension until now. For these readers, we hypothesized that most successful readers would be those who are able to construct a mental representation of the text's topic structure by slowing down the first-pass fixations on the topic-introducing sentences during initial reading (2b).

4.3. Method

4.3.1. Participants

Thirty-nine (9 male) students from the University of Turku, Finland, took part in the experiment for course credit. Their mean age was 24.82 years (SD = 5.53). All the participants were native speakers of Finnish and had normal or corrected-to-normal vision. Three participants had to be excluded due to poor calibration.

4.3.2. Apparatus

Eye-fixation data were collected with a desktop-mounted EyeLink 1000 eye-tracker manufactured by SR Research Ltd. (Mississauga, Ontario, Canada). Sampling frequency was 2,000 Hz; only the right eye was tracked. The stimuli were presented on a 21-inch CRT monitor with a screen resolution of 1,024 x 768 px and a 150 Hz refresh rate. Participants were seated 70 cm from the monitor. Forehead and chin rests were used to stabilize the head.

4.3.3. Texts

Two versions (refutation and non-refutation) of the text about the phenomenon of tides were used after translating it into Finnish. The text was divided into two pages. The first page presented information about the rotation of the Earth and Moon, and Newton's law of universal gravitation. This page was identical in both the refutation and non-refutation versions of the text. The second page introduced three distinct subtopics included in the general text topic, the phenomenon of tides: (1) The force of gravitational attraction from the Moon attracts both the terrestrial waters and rocks; (2) the phenomenon of high tide occurs twice a day; (3) the tides are caused by the joint forces of gravitational attraction from the Moon and Sun. These subtopics were chosen since they had been previously indicated as relevant to the topic of tides (Defrancesco & Oss, 2006; Sawicki, 1999; Viiri, 2000). The three subtopics were presented in separated paragraphs of text; each paragraph contained two sentence types, a topic-introducing sentence and sentences that elaborated on the information provided by the topic-introducing one (topic-progression sentences). The latter were non-topic sentences (Lorch, Lorch, & Matthews, 1985) and corresponded to the sentences named "topic-progression": "medial" and "end" sentences as used in Hyönä (1995) and Hyönä and Lorch (2004). The three subtopics reported in the second page were identical in the two text versions but were introduced by either refutation or filler (non-refutation) statements. An example of one of the refutation signals as well as its corresponding filler statement is: "Do you think that there is only one high tide per day? No!" (refutation); "The following is some information about the number of high tides per day" (filler). Figure 4.1. provides an example of the structure of the texts used.

The refutation version of the text was 231 words in length (the refutation statements comprised of 37 words) whereas the non-refutation version had 215 words (the filler statements comprised of 21 words). The part shared by the two versions of the text was 194 words in length. Both text versions were displayed in the Times New Roman 14 black font on a white background, and presented double-spaced on the screen. In the first reading, the second page of the refutation text included 17 lines whereas that of the non-refutation text included 16 lines. In the second reading, the second page of both versions of the text comprised 14 lines. The first page included 7 lines in both readings and text versions.

Figure 4.1. Example of a concept extracted from the texts.

	Refutation statement	***Filler (Non-refutation) statement***
	Do you think that there is only one high tide per day? No!	The following is some information about the number of high tides per day.
Topic-introducing sentence	There are two high tides a day, not only one.	
Topic-progression sentences	On one side of the Earth the waters rise because they are more strongly attracted by the Moon, while on the opposite side of the Earth the waters rise as well, moving away from the Earth to the opposite side of the Moon, since they are less strongly attracted by the latter, being more distant, and because of the centrifugal force.	

4.3.4. Procedure

Before starting the actual experiment, participants were asked to answer a prior knowledge question about the phenomenon of tides. Participants were then told that they would read a text about tides, and they were instructed to read the text for comprehension, imagining it was included in a textbook they had to study for an exam. They were also instructed to switch from the first to the second page of the text by pressing any button on a gamepad. Following, the eye-tracker was calibrated for each participant.

Participants were then given either the refutation or the non-refutation version of the text. Reading was self-paced with the restriction that returning to the first page from the second was prevented. At the end of the first reading, participants were instructed to reread the text and were given the same instructions as before, that is, to read it for comprehension. Furthermore, the eye-tracker was recalibrated. After that, participants read a text that was identical to that they had read before but wherein the refutation or the filler statements were removed. Finally, at the end of the second text reading, participants were asked to answer again the prior knowledge question, which served as a comprehension test question. The entire experimental session lasted approximately 45-50 minutes.

4.3.5. Dependent Variables

4.3.5.1. Eye-fixation measures. Four eye-fixation measures, computed for each of the target text sentences (topic-introducing and topic-progression sentences, and refutation vs. filler statements), served as dependent variables: *first-pass fixation time*, (2) *first-pass progressive fixation time*, (3) *first-pass reinspection time*, and (4) *look-back fixation time*.

All these eye-fixation measures were converted to time-per-character measures and logarithmically transformed, in order to control for the differences in length among the diverse sentence types and for the large inter-individual variability that lead to non-normal distributions, respectively.

4.3.5.2. Prior knowledge measure. Readers' misconceptions about the phenomenon of tides were evaluated by means of an open-ended question at the beginning of the experimental session. Two independent raters scored the readers' answers (% of agreement = 93.5) to verify whether they held misconceptions (score of 1) or did not (score of 0) about each of the three subtopics included in the text. The proportion of misconceptions found, averaged across the subtopics, was 79.3% (refutation text readers = 82.5%, non-refutation text readers = 75.9%).

4.3.5.3. Recall measure. Readers' comprehension performance was assessed by means of the same open-ended question given at the end of the two reading tasks. The two independent raters parsed the textual information provided in the topic-introducing and topic-progression sentences into 18 idea units. With a few exceptions, each idea unit corresponded to the core meaning of each topic-introducing and topic-progression sentence presented in the text. In particular, each of the three topic-introducing sentence contained one idea unit, while the topic-progression sentences of each subtopic, being more numerous, contained several idea units (range: 2-7). The two raters then scored whether each idea unit was (score of 1) or was not (score of 0) represented in the readers' recall protocols. Thus, the values of the recall scores were discrete (binomial) for both sentence types.

4.3.6. Data Analyses

Eye-fixation data were analyzed by means of mixed-effect multiple regression models in R (Baayen, 2011; Bates, Maechler, & Bolker, 2011; R Development Core Team, 2011, see Chapter 3).

Since the primary interest of the present study was in the effect of the text type (refutation vs. non-refutation) and sentence type on repeated reading, separate models were fitted for the topic-introducing and topic-progression sentences (which were read in both readings), and for the refutation vs. filler statements (which were only read in the first reading). The former models represented the models of main interest. Each model had one of the four eye-fixation measures as the dependent variable. Thus, a total of eight models were fitted, four for the topic-introducing and topic-progression sentences, and four for the refutation vs. filler statements. The models for the topic-introducing and topic-progression sentences included random effects for participant and subtopic[1], and repeated reading (first and second; within-subjects), text type (refutation and non-refutation; between-subjects), and sentence type (topic-introducing and topic-progression; within-subjects) as fixed effect factors. Given the primary interest of the study, only the two-way interactions between repeated reading and text type, and between repeated reading and sentence type, as well as the three-way interaction among repeated reading, text type, and sentence type were inserted in these models in addition to the main effects of these variables. Models for the refutation vs. filler statements comprised the same random effects (for participant and subtopic) as those for the topic-introducing and topic-progression sentences but, since the refutation and filler statements were only read in the first reading and in either text (refutation or non-refutation), they only included the text type (between-subjects) as fixed effect factor. In the models, all fixed effect factors (repeated reading, text type, and sentence type) were contrast coded: the first reading, the non-refutation text, and the topic-progression sentences served as baselines for comparison with the second reading, the refutation text, and the topic-introducing sentences, respectively.

Before fitting the models, the outliers on each eye-fixation measure were identified (i.e., values that fell beyond 3.0 SD from the mean). These outliers were removed from the respective datasets (one for each fitted model), and thus excluded from the statistical analyses, to avoid distortions of the model estimates due to extreme observations. The mean percentage of removed eye-fixation times (averaged across the datasets) was 0.7% (range: 0-2.1%).

The full specifications of the fixed and random effects of the models of main interest (the four models for the topic-introducing and topic-progression sentences) are reported in Appendix B.

[1] In both readings of the text, all participants read the same subtopics regardless of text type. Thus, participant and subtopic effects were crossed, not nested. In order to account for such a crossing, random effects for both participants and subtopic were inserted in all models (Baayen, 2008).

A generalized linear mixed-effects model (Baayen, 2008) was fitted to ensure the equivalence of the two groups of readers (refutation text, non-refutation text) for prior knowledge. The model included random effects for participant and subtopic, and text type (refutation and non-refutation, between-subjects) as fixed effect factor. Recall data were also analyzed by means of a generalized linear mixed-effects model including random effects for participant and subtopic, and text type (refutation and non-refutation; between-subjects) and sentence type (topic-introducing and topic-progression; within-subjects) as fixed effect factors. Consistently with the models for the eye-fixation measures presented above, in both these models the values and signs of the estimates of the fixed effects reflect the effects of the refutation text and topic-introducing sentences as compared to their baselines (the non-refutation text and topic-progression sentences, respectively).

Finally, four separate mixed-effects multiple regression models were fitted to test the effect of processing during rereading (eye-fixation measures) on readers' text recall scores, a model for each combination of text type (refutation and non-refutation) and sentence type (topic-introducing and topic-progression). In order to pair the recall scores with the data from the eye-fixation measures, the scores for the topic-progression sentences were averaged within each subtopic. Thus, in these models, the values of readers' text recall scores were binomial for the topic-introducing sentences and continuous for the topic-progression sentences. Consequently, the two models for topic-introducing sentences were generalized linear mixed-effects models, while those for topic-progression sentences were linear mixed-effects models. All models included random effects for participant and subtopic, and the three eye-fixation measures corresponding to the time course of processing during reading (first-pass progressive fixations, first-pass reinspections, and look-backs), and repeated reading (first and second; within-subjects) as fixed effect factors. Being continuous variables, the eye-fixation measures were grand-mean centered prior to the analyses (Baayen, 2008). As in all the models formerly described, the values and signs of the estimates of the variable of repeated reading reflected the effects of the second reading as compared to the first one.

4.4. Results

The section is arranged as follows: First, results from the model for readers' prior knowledge are introduced. Following, findings from the models for the processing of topic-introducing and topic-progression sentences, that is, the main models of interest, are presented, followed by the results from the models for the processing of refutation signals vs. filler statements. Finally, findings are reported from the analyses of readers' answers to the comprehension question and from those performed to investigate whether the eye-fixation measures predicted readers' text recall scores.

As described above (see the Method, Data Analyses subsections), the first reading for the fixed effect of repeated reading, the non-refutation text for the fixed effect of text type, and the topic-progression sentence for the fixed effect of sentence type, were used as the baseline. Thus, the values and signs of the estimates of the fixed effects reported below reflect the effects of the second reading, the refutation text, and the topic-introducing sentences as compared to their respective baselines.

Table 4.1. *Percentages (Frequencies in Parentheses) of Misconceptions by Text Type and Subtopic.*

	Refutation Text	Non-refutation Text	Total
1st Subtopic	94.7% (18/19)	88.9% (16/18)	91.8% (34/37)
2nd Subtopic	73.6% (14/19)	50.0% (9/18)	62.2% (23/37)
3rd Subtopic	79.0% (15/19)	88.9% (16/18)	83.8% (31/37)
Total	82.5% (47/57)	75.9% (41/54)	79.3% (88/111)

4.4.1. Readers' Prior Knowledge

Preliminary analyses were carried out on the readers' misconceptions to ensure the equivalence for prior knowledge of the two groups (refutation text readers, non-refutation text readers). Percentages and the associated frequencies are given in Table 4.1. Results from the model showed that the effect of text type did not prove significant ($p > .10$). No difference emerged between the readers of the refutation and non-refutation text in the proportion of misconceptions hold about the phenomenon of tides. This evidence reveals that the two groups of readers did not differ for knowledge before performing the reading task.

Table 4.2. *Means of Eye-Fixation Measures (in Log-Transformed Milliseconds-per-Character) by Repeated Reading, Text Type, and Sentence Type (Standard Deviations in Parentheses).*

	Topic-Introducing Sentences				Topic-Progression Sentences			
	R		NR		R		NR	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
First-pass Fixation Time	3.30 (0.56)	3.44 (0.65)	3.60 (0.55)	3.67 (0.69)	3.70 (0.59)	3.57 (0.48)	3.84 (0.53)	3.74 (0.40)
First-pass Progressive Fixation Time	3.11 (0.58)	3.20 (0.58)	3.39 (0.46)	3.32 (0.53)	3.03 (0.48)	3.09 (0.41)	3.12 (0.46)	3.13 (0.39)
First-pass Reinspection Time	0.93 (1.22)	1.22 (1.44)	1.57 (1.34)	2.05 (1.46)	2.76 (1.07)	2.28 (1.15)	2.92 (1.11)	2.69 (0.99)
Look-back Fixation Time	2.26 (1.46)	2.50 (1.62)	2.77 (1.50)	2.20 (1.70)	1.58 (1.41)	1.63 (1.42)	2.27 (1.54)	1.46 (1.30)

Note. R = Refutation text; NR = Non-refutation text; 1st = first reading; 2nd = second reading.

4.4.2. Processing of Topic-introducing and Topic-progression Sentences

The means and standard deviations for all eye-fixation measures are presented in Table 4.2.

4.4.2.1. First-pass fixation time. The results of the model for the first-pass fixation time showed that the main effect of text type, estimate = -0.11, t = -2.28, p = .015, and the main effect of sentence type, estimate = -0.11, t = -4.31, p = .0001, proved significant. In both readings, the refutation text readers spent shorter first-pass fixations on the whole text than readers of the non-refutation text, and all readers spent longer fixation time on topic-progression sentences than on topic-introducing sentences during the first-pass reading. In addition to these main effects, a significant interaction between repeated reading and sentence type also emerged, estimate = 0.05, t = 2.18, p = .032. Repetition produced different effects for the two types of sentences: topic-progression sentences received shorter first-pass fixations in the second reading than in the first reading of the text; on the other hand, first-pass fixation time devoted to the topic-introducing sentences increased from the first to the second reading. The other two-way interactions included in the model, as well as the three-way interaction between repeated reading, text type, and sentence type, did not result in significant effects (all ps > .10).

The full specifications of the fixed and random effects of the model for the first-pass fixation time are reported in Table B1 and Table B5, respectively (see Appendix B).

First-pass fixations were further divided into progressive and reinspective fixations in order to examine in more detail the processing time course during the first-pass reading.

4.4.2.2. First-pass progressive fixation time. The results from the model for the first-pass progressive fixation time showed only a significant main effect of sentence type, estimate = 0.08, t = 3.75, p = .0001. Readers made longer first-pass progressive fixations on topic-introducing sentences than on topic-progression sentences in both readings and text types. The two-way and three-way interactions included in the model were not significant (all ps > .10).

The full specifications of the fixed and random effects of the model for the first-pass progressive fixation time are reported in Table B2 and Table B5, respectively (see Appendix B).

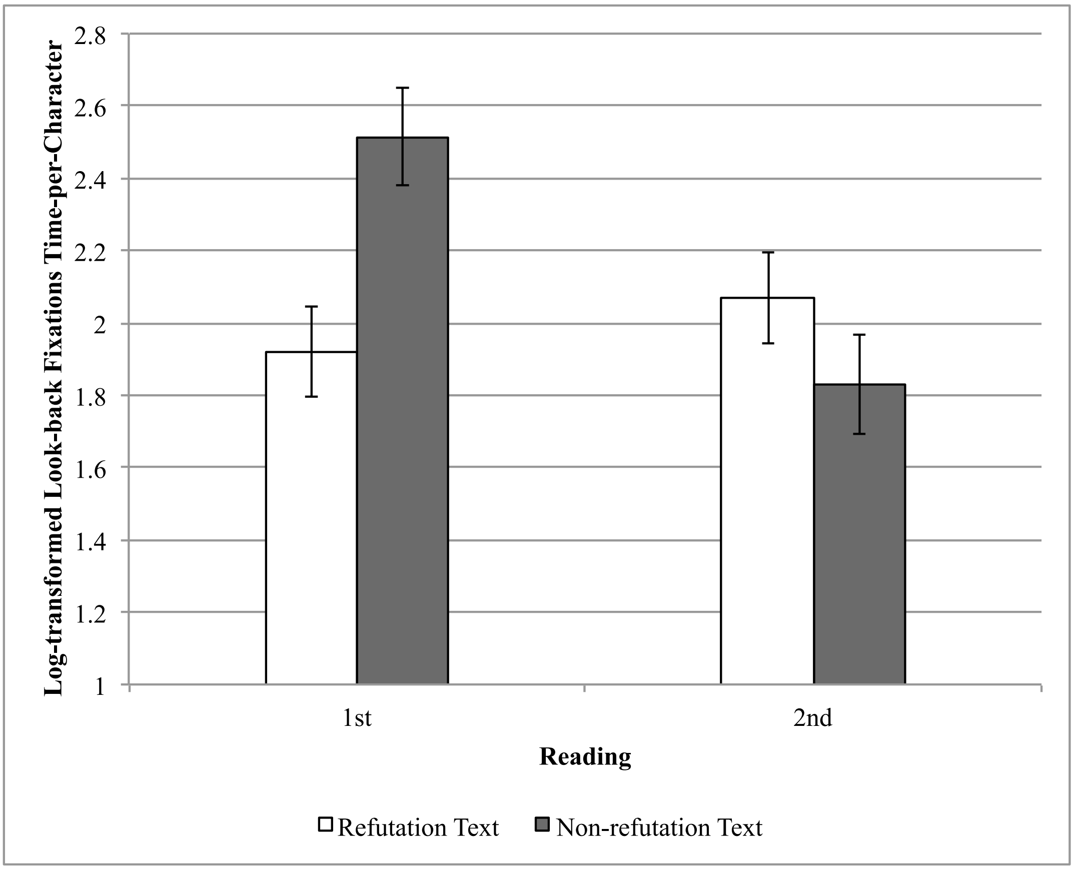
4.4.2.3. First-pass reinspection time. Regarding the first-pass reinspection time, findings from the model revealed that the text type, estimate = -0.25, t = -2.80, p = .004, and sentence type, estimate = -0.61, t = -11.09, p = .0001, resulted in significant effects. First, the reinspections of non-refutation text readers were longer than those made by readers of the refutation text. Second, more first-pass reinspection time was spent when reading topic-progression sentences than topic-introducing sentences. Furthermore, the interaction between repeated reading and sentence type proved significant, estimate = 0.19, t = 3.36, p = .002. This result was very similar to that emerged in the model for the first-pass fixation time: Readers spent less first-pass reinspection time during the second reading of the topic-progression sentences than in their first reading; in contrast, the summed duration of first-pass reinspections devoted to the topic-introducing sentences increased from the first to the second reading. Anyway, as it appears from the means reported in Table 4.2., the decrease of the fixations duration on the topic-progression sentences and its increase on the topic-introducing sentences were both stronger for the reinspective fixations than for the entire first-pass fixation time. The estimates of the other two-way interactions and that of the three-way interaction included in the model did not reach significance (all ps > .10).

The full specifications of the fixed and random effects of the model for first-pass reinspection time are reported in Table B3 and Table B5, respectively (see Appendix B).

4.4.2.4. Look-back fixation time. The results from the model for the look-back fixation time showed the significant main effects of repeated reading, estimate = -0.14, t = -2.50, p = .020, and of sentence type, estimate = 0.35, t = 6.48, p = .0001. Overall, the look-backs were shorter in the second reading than in the first reading of the text. In addition, look-back fixation time on topic-introducing sentences was generally longer than that on topic-progression sentences. Furthermore, the two-way interaction between repeated reading and text type proved significant, estimate = 0.21, t = 3.86, p = .0002 (Figure 4.2.). Unlike the readers of the non-refutation text, who spent less look-back fixation time in the second reading than in the first reading of the text, the refutation text readers made longer look-back fixations during the second than the first reading. The other two-way interactions as well as the three-way interaction included in the model did not reach significance (all *p*s > .10).

The full specifications of the fixed and random effects of the model for look-back fixation time are reported in Table B4 and Table B5, respectively (see Appendix B).

Figure 4.2. Estimates Means (and Standard Errors) of Look-back Fixation Time by Repeated Reading and Text Type.



4.4.3. Processing of Refutation vs. Filler Statements

Regarding the processing of refutation vs. filler statements, the results showed no effect of text type in any model (all *p*s > .10). No difference emerged between the readers of the refutation and non-refutation text either in the first-pass reading (first-pass, first-pass progressive, and first-pass reinspection time) or in the second-pass reading (look-back fixation time) of those statements. This pattern of results demonstrates that the refutation and filler statements were processed equally during reading.

4.4.4. Readers' Recall and Processing during Rereading

Additional analyses were conducted on the readers' text recall scores to examine whether the text type and sentence type had an effect on their memory for the information presented in the text. The percentages and the associated frequencies are given in Table 4.3. Following, it was also investigated whether readers' memory performance was predicted by the online processing during rereading, as reflected in the eye-fixation measures.

Results from the model for recall data showed that the main effect of sentence type proved significant, estimate = 1.23, z = 8.20, p = < .0001. Readers of both texts recalled better the idea units included in the topic-introducing sentences than those comprised in the topic-progression sentences. The main effect of text type and the interaction between text type and sentence type did not result in significant effects (all ps > .10).

Table 4.3. *Percentages (Frequencies in Parentheses) of Idea Units Reported in Recalls (Score of 1) by Text Type and Sentence Type.*

	Refutation Text	Non-refutation Text	Total
Topic-introducing Sentences	87.7% (50/57)	80.4% (41/51)	84.3% (91/108)
Topic-progression Sentences	35.8% (102/285)	34.5% (88/255)	35.2% (190/540)
Total	44.4% (152/342)	42.2% (129/306)	43.4% (281/648)

4.4.5. Effect of Processing during Rereading on Readers' Recall

As concerns the model for topic-introducing sentences and the refutation text, results showed that the main effect of first-pass reinspection time, estimate = -0.76, z = -2.05, p = .040, proved significant. The shorter the first-pass reinspective fixations of refutation text readers on the topic-introducing sentences, the higher their scores. With respect to the model for topic-progression sentences and the refutation text, it revealed the significant main effect of look-back fixation time, estimate = 0.04, t = 1.71, p = .047. The longer the look-backs of refutation text readers on the topic-progression sentences, the deeper their comprehension. Regarding the model for topic-introducing sentences and the non-refutation text, findings showed a significant interaction between first-pass progressive fixation time and repeated reading, estimate = -2.13, z = -2.11, p = .034. The longer the first-pass progressive fixations of non-refutation text readers on the topic-introducing sentences in the initial reading, and the shorter in the second reading, the better the recall. No significant effects emerged from the model for topic-progression sentences and the non-refutation text (all ps > .10).

4.5. Discussion

The present study was aimed at documenting that text processing during repeated reading embodies a strategic component and that providing readers with a refutation text (wherein information is signaled by statements of the misconceptions a reader may hold about a natural phenomenon) is a means to uncover the strategic component. In addition, the effect of refutation statements on the processing of the text's topic structure was also considered, together with the effect of the online processes on readers' memory performance. Three main research questions guided the study. The first question asked whether the presence of refutation statements would impact on the way in which readers process the text during rereading. The second question asked whether the refutation text would facilitate the processing of topic-introducing sentences in the initial reading. Finally, the third question asked for what online processes would predict the memory performance of refutation and non-refutation text readers.

Regarding the first research question, results suggest that the repeated reading benefit is in part strategic in nature and that signaling of refutation encourages strategic behavior during rereading. Readers of the refutation text spent more time in looking back the text information during rereading than during the initial reading, whereas the duration of look-backs of non-refutation text readers decreased from the first to the second reading, showing the facilitatory effect already found in previous research using eye movements (Hyönä & Niemi, 1990; Raney & Rayner, 1993, 1995; Schnitzer & Kowler, 2006). In order to account for this pattern of results, it is convenient to refer to refutation statements as advanced organizers. Signaling devices (e.g., headings, previews, overviews, and summaries) have been described as advanced organizers as they provide the readers with concise statements of the information they are about to encounter while reading, thus relieving them from inferring this information from the text and providing them with a coherent plan for retrieving information from memory (Lorch, 1989; Lorch & Lorch, 1995). Recent research (Kendeou & van den Broek, 2007; van den Broek & Kendeou, 2008) has pointed out that refutation statements, which represent a peculiar kind of signaling device, also act as advanced organizers. It is then arguable that refutation statements provide the readers with a plan to retrieve from memory relevant knowledge associated with the text information. This explains why, in the initial reading wherein text information was signaled by either refutation or general relevance signaling, the refutation text readers needed to backtrack less in the text than the non-refutation text readers.

Regarding the behavior of refutation text readers during rereading, it can be explained on the basis of the context-dependent representation model for explaining text repetition effects (Raney, 2003). Raney's (2003) context-dependent model builds upon Kintsch's model (1988, 1998) of text comprehension and proposes that the textbase and situation model reflect different degrees of context dependence. According to Raney's (2003) model, the textbase is represented in a context-independent manner, and a well-developed situation model binds together the textbase, thereby creating a context-dependent representation. Establishing a well-developed situation model leads to context-dependent representations, which in turn leads to context-dependent repetition effects. Hence, if the textbase is reinstated in the context of different situation models there is little to no repetition benefit. With respect to the present study, refutation text readers were provided with a text whose textbase, corresponding to the scientific explanations, was more strongly bound together with its context, represented by the ideas about the topic discussed in the text, including the misconceptions stated in the refutation statements. In this respect, the refutation statements provided a context to the scientific explanations. Consequently, the discrepancy between the situation models in the first and second reading was larger for refutation text readers, who needed to re-activate the information presented in the refutation signals during rereading. This, in turn, resulted in a repetition cost (Levy, 2001; Millis & Simon, 1994; Millis, Simon, & tenBroek, 1998).

With respect to the second research question, concerning the processing of the text's topic structure (topic-introducing vs. topic-progression sentences) across repeated reading, two are the main outcomes emerged. First of all, the two diverse sentence types within text topic structure were attended differently as a function of the time course of processing during reading. Interestingly, topic-introducing sentences were processed more deeply in the earlier (first-pass progressive fixations) and more delayed (look-back fixations) stages of processing, while topic-progression sentences received longer fixations particularly during first-pass rereading (reinspective fixations). The evidence regarding the topic-introducing sentences is not surprising, since it further emphasizes the importance of this kind of sentences within the hierarchical structure of the text, replicating the findings by Hyönä (1995; see also Hyönä & Lorch, 2004). It is remarkable that the higher prominence of these sentences impacted on the reading processing at its very beginning and at its end. Readers probably slowed down the reading when first encountering the topic-introducing sentences in order to "map" the text and yield its hierarchical structure. As this process was accomplished, they could strategically concentrate more on the most important sentences within the text, those that are crucial for adequately comprehending it, namely, the topic-introducing sentences again.

In contrast, the pattern of processing of the topic-progression sentences is more difficult to interpret. On one hand, this evidence failed to replicate previous findings (Hyönä & Lorch, 2004); on the other, it is consistent with the results of Hyönä and Niemi' (1990, Experiment 2) study, wherein readers were also given a text to read repeatedly. The topic-progression sentences used in the present study were similar to the sentences included in the "detailed coverage" section of the text used in Hyönä and Niemi (1990, Experiment 2). The information provided in the topic-progression sentences were denser than those included in the topic-introducing sentences, as the information provided in the "detailed coverage" section were denser than those included in the "introduction" section of the Hyönä and Niemi text. Specifically, in each subtopic, topic-progression sentences were more (range: 2-7) than topic-introducing sentences, which were only one per subtopic. Kintsch and Keenan (1973) have pointed out that the more information a sentence (or, as in the present case, a group of sentences) entails, the longer it takes to read. This explains why all the readers spent more first-pass reinspection time while reading the topic-progression sentences - as the readers of Hyönä and Niemi (1990, Experiment 2) did while reading the "detailed coverage" section -, because they comprised more information than topic-introducing sentences.

The second outcome emerged is perhaps more interesting, since it directly concerns how the topic-introducing sentences and topic-progression sentences were processed across repeated reading. Overall, the fixations of non-refutation text readers were longer than those made by readers of the refutation text. Topic-progression sentences were processed for shorter in the second reading than in their first reading; in contrast, the processing time spent on the topic-introducing sentences increased from the initial to the second reading of the text. These results emerged in two models out of four: the model for the entire first-pass fixation time and that for the first-pass reinspection time. Thus, the effect on the entire first-pass fixations was determined by the effect on the reinspective fixations. For this reason, and since the effect on reinspections was showed to be stronger than the effect on the entire first-pass fixations, only the former will be discussed. The processing of topic-introducing sentences was more facilitated during the initial reading of the text than in the rereading. This was probably due to the fact that, as predicted by the "Landscape Model" (van den Broek & Kendeou, 2008; van den Broek et al., 1996, 1999), the information provided in the refutation signals, that is, the misconceptions the readers may hold about the topic discussed in the text, acted as advanced organizers of refutation text reading, thus facilitating the processing of topic-introducing sentences. It is also possible that refutation signals, highlighting possible inconsistencies between readers' prior conceptions and text information, made topic-introducing sentences more interesting to attend; this higher interest was reflected in facilitated processes (Broughton et al., 2010).

Noteworthy, when readers were given the text to reread, topic-introducing sentences were attended for longer than in the initial reading, while first-pass reinspection time on topic-progression sentences considerably decreased. This evidence contradicts what was found in the study by Hyönä (1995), wherein the facilitatory effect due to rereading emerged for both sentence types and was substantially stronger for topic-introducing (topic-shift) sentences than for topic-progression sentences. To account for this inconsistency with the previous research, it is useful to recall how the texts were organized. In the initial reading, both versions of the text were signaled either by refutation statements or sentences that anticipated the content of the text. It is so arguable that the topic-shift effect was modulated by such signals. This effect is similar to what was found by Hyönä and Lorch (2004), wherein the online processing of topic-introducing sentences signaled by headings required less resources than the processing of topic sentences without headings. As discussed above, the effect of refutation signals was stronger than the effect of filler statements. In contrast, during rereading, the texts were not signaled. Thus, readers needed to slow down the processing of topic-introducing (topic-shift sentences), in order to construct a mental representation of the text's topic structure. As a matter of fact, in the rereading, when readers read text information without signals, the topic-introducing sentences turned to serve as the site of the topic-shift effect, thereby an increase in the duration of readers' reinspective fixations was observed.

Regarding the third research question, focused on whether the eye-fixation measures predicted readers' recall, three were the results emerged; two of them regarded refutation text readers and one the readers of the standard, non-refutation text. For what concerns the readers of the refutation text, the shorter their first-pass reinspective fixations on the topic-introducing sentences, and the longer their look-backs on the topic-progression sentences, the deeper their comprehension. This means that, among refutation text readers, those who experienced fewer difficulties and could be more strategic during reading achieved the higher outcomes. On the other hand, for non-refutation text readers, the longer the first-pass progressive fixations on the topic-introducing sentences in the initial reading, and the shorter in the second reading, the better the recall. This pattern of results further supports what has been already argued about the effects of text's topic structure on the processing during rereading. Readers of the standard, non-refutation text who showed a better recall were those who constructed a stable mental representation of the text at the end of the initial reading by engaging more in progressive fixations on the topic-introducing sentences (a peculiar characteristic of refutation text readers) and then needed to reinstate these sentences for shorter while rereading (Hyönä, 1995). These latter analyses concerning readers' comprehension performance and its relationship with the eye-fixation measures are notable, since they contribute to elucidate what emerged in the models of main interest about reading processing.

Chapter 5

Fourth Study
The Interplay of Refutation Text and Working Memory on Processing during Reading

5.1. The Study

The last study focused on the interplay of refutation text and the individual characteristic of working memory on cognitive processing during reading. Specifically, it investigated the online processing of readers with different working memory capacity (lower-span and higher-span readers) while reading either a text with a refutation structure, or a text with a standard structure. The objective was to examine whether the two types of text would induce different processing for students with different working memory during reading. In addition, it was investigated whether online processing, in particular the co-activation of alternative and scientific conceptions, would contribute to offline learning from text.

5.2. Research Questions and Hypotheses

Specifically, four research questions guided our study. The first referred to the offline products of reading: (1) Is the refutation text particularly effective for readers with a lower verbal working memory capacity? The second and third research questions referred to online processing during reading: (2) Do both lower-span and higher-span readers of the refutation text co-activate more strongly the scientific information and their inaccurate conceptions during reading? (3) Does a refutation text facilitate the elaboration of text information compared with a non-refutation text, particularly during the second-pass reading (look-back fixations)? Lastly, the fourth research question concerned the link between the online processes and the offline products of reading: (4) Is the refutation text readers' better learning performance related to their stronger co-activation of scientific conceptions and inaccurate ideas, which is a crucial predictor of learning from text?

Four hypotheses were formulated. (1) Refutation text would promote a deeper comprehension of the scientific conceptions presented in the text as documented in previous research. In particular, we expected that higher-span readers of the refutation text would attain a better learning performance, while the weakest learning gains would be that of lower-span readers of the non-refutation text. Moreover, lower-span readers would benefit particularly from reading a refutation text that scaffolds them during processing. As a consequence, their knowledge gains would be higher than the gains of lower-span readers in the non-refutation group. In contrast, the learning performance of high-span readers would be similar in the two reading conditions. (2) Differences in cognitive processing between the higher and lower-span readers of the refutation or non-refutation text would be revealed during the second-pass reading, which indicates, on the one hand, the readers' attempts to resolve comprehension difficulties during reading (Rayner, 1998, 2009) and, on the other, can reflect a more strategic and purposeful reading behavior (Hyönä, Lorch, & Kaakinen, 2002; Hyönä & Nurminen, 2006). We predicted that all readers of the refutation text would co-activate the scientific conceptions and inaccurate conceptions more strongly than both lower-span and higher-span readers of the non-refutation text. A stronger co-activation would be revealed by their longer *look-froms*, reflecting the time spent refixating the refutation segments, using the segments where the scientific conceptions are introduced as the anchor point of the rereading sequences. The particular text structure would support the simultaneous processing of alternative and scientific conceptions. (3) The refutation statements would also facilitate readers in processing text information, as revealed by the shorter *look-back fixation time* of refutation text readers in both working memory groups. Specifically, either refutation text readers or readers with a higher working memory capacity span would need to backtrack text information less. Therefore, the prediction was that lower-span readers of the non-refutation text would be the group with the longer look-backs in the text, whereas higher-span readers of the refutation text would be the most facilitated. (4) The higher learning performance of the refutation text readers would be predicted by the co-activation of alternative and scientific conceptions, that is, by *look-from fixation time* during reading, after controlling for reading time, prior knowledge, and working memory capacity. Co-activation was presumed to facilitate the detection and solution of inconsistencies between the scientific conceptions and readers' own conceptions, an essential step for the integration of prior and new conceptions about the scientific phenomenon to be learned.

5.3. Method

5.3.1. Participants

Sixty-three (38 female) undergraduate students of psychology from a large public university in north eastern Italy took part in the study on a voluntary basis. They were in their fourth year of study at university and their mean age was 23.8 years (SD = 2.8). They met the prior knowledge inclusion criterion by scoring 60% or lower in the measure used as pretest knowledge about the phenomenon of tides (see below), which suggests that they held alternative conceptions about this phenomenon. All students were Caucasian with normal or corrected-to-normal vision and Italian was their native language. All could be considered as competent readers. A reading test was not administered, since it is not available for university Italian students. However, their reading ability was considered at least sufficient, as they had passed the entrance examination for admittance into a psychology undergraduate program, part of which includes a reading comprehension test. Students with a low score are not admitted.

Of these students, four were outliers on at least one of the measures of cognitive processing during reading (eye-fixation measures). Given that their performances were greater or lower than 3.0 standard deviations from the mean, they were removed from all analyses. Therefore, data from fifty-nine (35 females) students were considered in the statistical analyses.

Participants were divided into four groups, each corresponding to a combination of text type and level of working memory capacity: refutation text/lower span readers, refutation text/higher span readers, non-refutation text/lower span readers, non-refutation text/higher span readers. There were 14 participants in each of the two refutation conditions (lower and higher span readers), while the two non-refutation conditions comprised 16 lower span and 15 higher span readers.

5.3.2. Texts

The refutation and standard texts about the phenomenon of tides had already been used in the first study (see Chapter 2).

5.3.3. Apparatus

Eye movements were collected using the Tobii T120 eye-tracker, manufactured by Tobii Technology (Stockholm, Sweden), already used in the first and second studies (see Chapters 3 and 4).

5.3.4. Pre and Posttest Measures

Participants' knowledge at pre and posttest was measured by five questions: two multiple-choice questions about Newton's Universal Gravitational Law (Cronbach's α = .66 at pretest and .74 at posttest) and three open-ended questions about the phenomenon of tides (Cronbach's α = .64 and .70 at posttest). Reliability estimates for both kinds of question were lower than desired. However, they are still within the acceptable range as argued in the literature about psychometric properties of scales developed for research purposes (Nunnally, 1978). The two multiple-choice questions about Newtonian mechanics were: "What is the force that causes the tides?" and "Two asteroids are at a distance of 2 km from each other. The first asteroid has a mass of 10 kg, while the mass of the second asteroid is 8 kg. What is the force of reciprocal attraction between the two asteroids?". For both questions, there were three possible answers: One scientifically correct (score 1), one naïve (score 0), and one distracter (score 0). The three open-ended questions examined participants' conceptions of the three crucial aspects of the phenomenon, about which misconceptions are very common, as stated above (Sawicki, 1999; Viiri, 2000): 1. "What is the astronomical cause of tides?"; 2. "On one side of the Earth there is a high tide. What is the tide like on the other side at the same moment?"; 3. "The moon attracts the earth. What parts of the earth are attracted?". Two independent raters coded the answers to these open-ended questions. They scored a completely alternative answer 0, a partly correct answer 1, and a correct and complete answer 2. It should be noted that no answers scored 2 in the first and third questions at the pretest. In this regard, we analyzed the frequency of the three alternative conceptions among participants. The first one was held by 95% of participants, the second by 82%, and the third by 83%. In addition, 5% of participants had a partially incorrect conception about the first scientific concept (what the moon attracts), 5% about the second concept (the number of tides per day), and 17% about the third (not only lunar attraction causes tides). It should be noted that only 13% of participants had two alternative conceptions about tides, whereas all the other participants held all three misconceptions.

As revealed by Cohen's *k*, inter-rater reliability ranged from .80 to .94 at the pretest and from .92 to .94 at the posttest. Disagreements were resolved through discussion.

Participants' total scores for knowledge at pre and posttest were calculated by summing up the scores of all five questions.

5.3.5. Verbal Working Memory Capacity

Participants' verbal working memory capacity was assessed by means of the Italian version of Daneman and Carpenter's (1980) Reading Span Test (Pazzaglia, Palladino, & De Beni, 2000), which requires the simultaneous processing and storage of unrelated information and is, therefore, considered a complex span text. It included 80 clauses presented sequentially, one at a time, at the center of a white computer screen, and arranged in groups ranging from a minimum of two to a maximum of six clauses. The groups were separated by a blank screen of a different color (grey). In the test, each group comprising a particular number of clauses was repeated four times (i.e., there were four groups of two clauses, four groups of three clauses, etc.). During the Reading Span Test, participants were first asked to read aloud all 80 clauses and, immediately after reading each clause, to say whether it was true or false. Participants were then asked to remember, at the end of each group of clauses, the last word of each clause in the correct order. Their scores for verbal working memory capacity were obtained by summing all the last words remembered in the correct order.

A median split was used to assign the participants to lower and higher-span groups. The lower-span group (scores 32-49) comprised thirty participants (14 in the refutation condition and 16 in the non-refutation) and the higher-span group (50-73) twenty-nine participants (14 in the refutation condition and 15 in the non-refutation). We acknowledge that a median split on working memory capacity may be somewhat arbitrary and result in some loss of accuracy due to the truncation of the range of scores into a dichotomous variable. Still, our focus on groups of readers with different working memory capacity and the implications of group membership for performance in different task conditions seemed to outweigh this potential disadvantage. Moreover, the median-split procedure is commonly used when working memory capacity is studied (Soederberg Miller, Cohen, & Wingfield, 2006; vonHecker & Dutke, 2004), particularly when its interplay with other variables is taken into account (e.g., Allowey, Banner, & Smith, 2010; Grimley & Banner, 2008).

5.3.6. Eye-fixation Measures

One general measure of first-pass reading, the *first-pass fixation time*, and two measures of second-pass reading, the *look-back fixation time*, and *look-from fixation time* were used as indices of cognitive processing during text reading. *Look-from fixation time* was used as the index of co-activation of segments that span a relatively long distance within a text, that is, simultaneous processing of scientific and alternative conceptions about the topic.

The three eye-fixation measures were computed for each of the eight areas of interest included in each text. Given that both the texts as a whole and their component parts were identical for the number of sentences, words, and characters, the use of a ratio-per-character procedure to reduce the eye-fixation data was not necessary (Kaakinen, Hyönä, & Keenan, 2003).

5.3.7. Procedure

In a department laboratory equipped with the Tobii T120 eye-tracker, participants were first asked to indicate their gender and age, and answer the prior knowledge questions. They were then given either the refutation or non-refutation text to read while their eye movements were monitored. As in the other experiments that concurrently measure readers' eye movements and verbal working memory capacity (e.g., Kaakinen, Hyönä, & Keenan, 2003), participants completed the Reading Span Test, which also acted as a distracter, after the reading task and before measuring learning performance. Finally, participants were again asked the same initial questions as the posttest measure. The entire procedure took about 45-50 minutes.

5.3.8. Data Analyses

Data analyses were conducted as follows. Preliminary ANOVAs were performed to ensure the equivalence of the readers for prior knowledge and reading time in the four reading groups: refutation text/lower span, refutation text/higher span, non-refutation text/lower span, and non-refutation text/higher span. We then tested whether learning gains were different as a function of the four readers' group by means of a 4 (reading group, between-subject) × 2 (time, within-subject) mixed-factor design. After, we analyzed the online processing of the different text segments (refutation vs. filler statements and segments introducing the scientific concepts) through ANCOVAs with the readers' group as the independent variable, reading time as a covariate, and each eye-fixation measure (first-pass fixation time, look-back fixation time, and look-from fixation time) as the dependent variables. Finally, in order to investigate the link between offline outcomes of learning from text and online processes during reading, we performed separate multiple hierarchical regression analyses for each text type (refutation, non-refutation) and level of working memory capacity (lower span, higher span) with the eye-fixation measures as predictors and scores at posttest as the dependent variable.

5.4. Results

5.4.1. Preliminary Analyses

The preliminary analyses showed no statistically significant differences between the four groups for prior knowledge, $F(3, 55) = 1.14$, $p = .342$, or reading time, $F(3, 55) = .24$, $p = .868$.

5.4.2. Offline Learning: Effectiveness of the Refutation Text

After the preliminary analyses, it was examined the offline products of reading comprehension to determine whether the refutation text readers with higher working memory capacity were those who reached the highest learning outcomes. In addition, it was examined whether the effectiveness of the refutation text over the standard text was more evident among the readers with lower working memory capacity. A mixed-factor design with testing time (pretest, posttest) as the within-subject variable and the four reading groups (refutation text/lower span, refutation text/higher span, non-refutation text/lower span, and non-refutation text/higher span) as the between-subject variables was carried out. It revealed the main effect of time, $F(1, 55) = 257.94$, $p < .001$, $\eta^2 = .88$, whereas the main effect of reading group was not significant ($p > .10$). Overall, the readers of either the refutation or the standard text significantly improved their knowledge about tides as an effect of reading.

The interaction time x reading groups, $F(3, 55) = 5.86$, $p = .002$, $\eta^2 = .08$, was also significant (Figure 5.1.). Bonferroni-adjusted multiple comparisons showed that higher-span students who received scientific information from the refutation text benefited more from reading than lower-span readers of the standard, non-refutation text ($p = .013$) (Table 5.1).

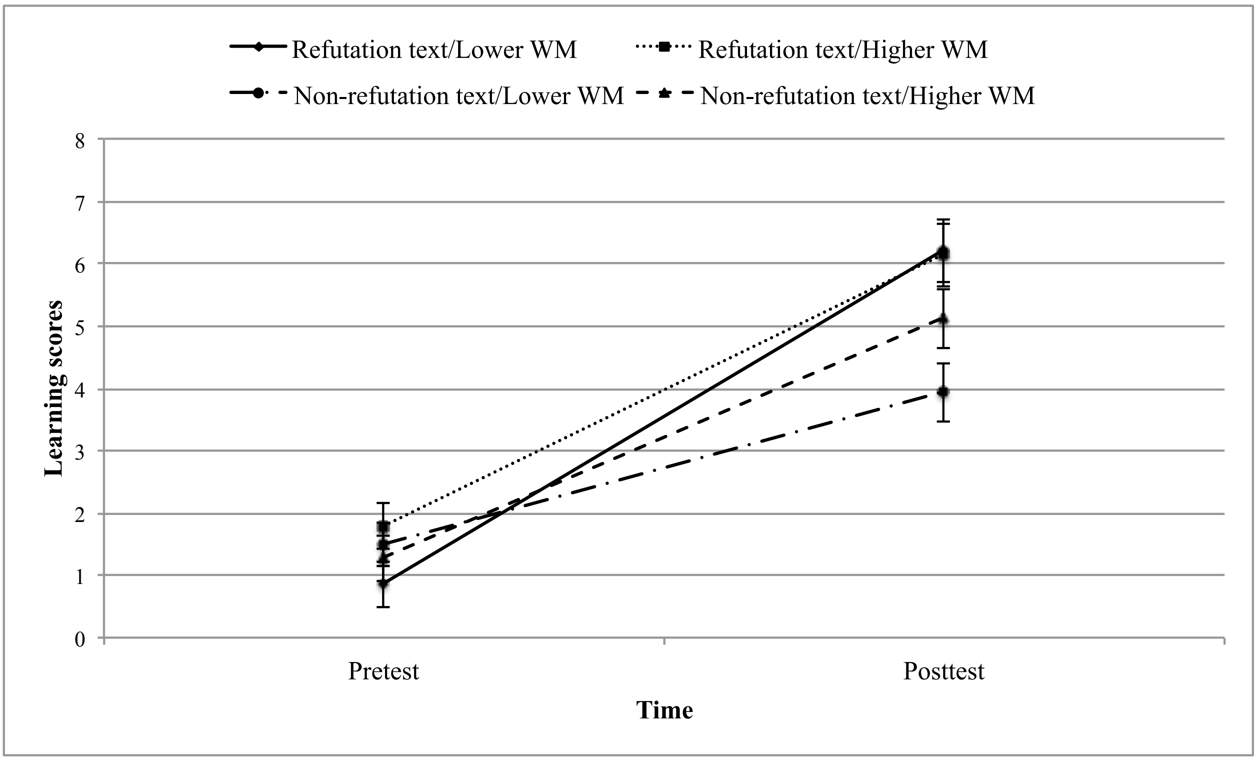
Readers of the refutation text with lower working memory capacity benefited particularly from this text structure as they outperformed the corresponding readers of the non-refutation text ($p = .010$) (Table 5.1.). In contrast, no significant differences emerged between the two reading conditions for readers with higher working memory capacity ($p > .10$).

Table 5.1. *Adjusted Marginal Means and Standard Errors of Learning Scores at Pre and Posttest by Reading Group.*

	Refutation text				Non-refutation text			
	Lower WM		Higher WM		Lower WM		Higher WM	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Pretest	.86	.37	1.79	.37	1.50	.35	1.27	.36
Posttest	6.21	.50	6.14	.50	3.94	.47	5.53	.48

Note. Scores range 0-8; WM = Working memory.

Figure 5.1. Adjusted Marginal Means of Learning Scores at Pre and Posttest by Reading Group.



5.4.3. Online Text Processing: Co-activation during Reading

Online cognitive processing during text reading was revealed by eye-fixation measures. Preliminarily, it was ensured that there were no threats to the validity of the non-refutation text due to the content of its introduction. To this aim, two separate ANCOVAs were performed, with the four groups (refutation/higher span, refutation/lower span, non-refutation higher span, and non-refutation lower span) as independent variable, the first-pass and look-back fixation time spent on the introduction of both texts as dependent variables, and reading time as covariate. Findings showed that there were no differences (both *p*s > .10) between the four groups in the fixation time spent during both the first- and second-pass reading of the introductions. On the basis of these results, we concluded that lower and higher-span readers in both conditions spent the same time reading the first segment of the text.

Following, the analyses of interest regarding the differences between the four reading groups during the second-pass reading, which may reveal a more strategic and purposeful text processing, were carried out. Specifically, the interest was in considering look-from fixation time as an index of the simultaneous activation of earlier and successive text information. In this regard, the time readers spent backtracking the segments stating their own alternative conceptions while reading the segments presenting the new scientific conceptions was examined.

An ANCOVA with reading group as the independent variable, look-from time as the dependent variable, and reading time as a covariate was carried out. Reading time was included as a covariate to control for a factor that could have influenced the results of eye-fixation durations. The ANCOVA revealed the significant effect of reading group, $F(3, 54) = 4.96$, $p = .004$, $\eta^2 = .09$ (Table 5.2.). Bonferroni-adjusted multiple comparisons between groups showed that both lower span ($p = .003$) and higher span ($p = .040$) readers of the refutation text directed more visual attention to the segments that challenged their current conceptions while reading the scientific concepts than higher span readers of the non-refutation text.

No significant differences emerged between the two groups of refutation text readers and the lower span readers of the non-refutation text, or between the two groups of non-refutation text readers (all *p*s > .10). The covariate of reading time, $F(1, 54) = 90.75$, $p < .001$, $\eta^2 = .56$, was also significant.

In addition, an ANCOVA with reading group as the independent variable, look-back fixation time as dependent variable, and reading time as a covariate, revealed the significant effect of reading group, $F(3, 54) = 3.67$, $p = .018$, $\eta^2 = .08$ (Table 5.2.). Bonferroni-adjusted multiple comparisons showed that both lower span ($p = .040$) and higher span ($p = .036$) readers of the standard text backtracked the scientific concepts for longer than higher span readers of the refutation text. No significant differences emerged between the two groups of non-refutation text readers and the lower span readers of the refutation text, or between the two groups of refutation text readers (all *p*s > .10). The effect of the covariate of reading time, $F(1, 54) = 108.11$, $p < .001$, $\eta^2 = .62$, also reached significance.

No significant differences in online processing of the various text segments emerged between the four groups during the first-pass reading (all *p*s > .10).

Table 5.2. *Adjusted Marginal Means and Standard Errors (in milliseconds) of Look-from and Look-back Fixation Times by Reading Group.*

		Look-back fixation time		Look-from fixation time	
		M	*SE*	*M*	*SE*
Refutation text	Lower WM capacity	27,069.59	1,867.77	31,830.43	1,746.74
	Higher WM capacity	20,710.08	1,863.07	29,581.01	1,742.35
Non-refutation text	Lower WM capacity	27,936.96	1,749.10	27,257.29	1,635.76
	Higher WM capacity	28,124.95	1,799.70	22,917.48	1,683.08

Note. Adjustment by covariate of reading time.

5.4.4. Link Between Text Processing and Learning from Text

The link between online text processing and offline learning from text was examined using a hierarchical multiple regression analysis for each text type (refutation, non-refutation) and level of working memory capacity (lower span, higher span). Scores for the offline measure of conceptual learning were used as the criterion variable. For the regressions regarding text type, in the first step the predictors were prior knowledge, working memory capacity, and reading time. The regression model for these variables did not account for a significant variance in the learning scores obtained by refutation-text readers, $F(3, 24) = 2.59$, $p = .077$. In the second step, the predictors were the eye-fixation indices that differentiated the four groups of readers in the analyses of online processing: look-back fixation time on the scientific concepts and look-from fixation time indexing the time spent by readers refixating the segments stating their own alternative conceptions while reading the segments presenting new scientific conceptions. The regression model for these indices of online processing accounted for a significant 51% of the variance, $F(5, 22) = 4.50$, $p = .006$, with an increment of 27%. Specifically, learning from text was negatively predicted by reading time and positively predicted by look-from fixation time. Prior knowledge was also a predictor in the second step. The higher the student's pre-existing knowledge, the shorter the time spent reading the text, the longer the simultaneous processing of alternative and scientific conceptions, and the greater the learning from text (Table 5.3.).

For the non-refutation text readers, the regression model for prior knowledge, working memory, and reading time in the first step accounted for a significant 32% of the variance, $F(3, 27) = 4.14$, $p = .015$. Working memory capacity positively predicted what they learned from text. In contrast, the regression model for the eye-fixation indices in the second step did not account for any significant increment as learning from the non-refutation text was again predicted only by working memory capacity. This outcome indicated that the higher the readers' capacity to process and temporarily store information while reading, the greater their knowledge gains (Table 5.3.).

For further control, similar regression analyses separated for each level of working memory capacity were performed. As an extra confirmation of the learning outcomes, these analyses revealed that in the second step, the refutation text ($\beta = .74$, $p < .01$) predicted significantly the conceptual learning of lower-span readers only, $F(3, 26) = 10.28$, $p < .001$.

Table 5.3. *Summary of Regression Analyses for Variables Predicting Learning from Text Type.*

Variable in Equation	*B*	*SE B*	*β*
Refutation Text			
Step 1			
Reading Time	0.57	0.25	0.29
Prior Knowledge	0.46	0.24	0.36
Working Memory Capacity	0.04	0.51	0.15
R^2	0.24		
Step 2			
Reading Time	-2.40	0.99	-1.23*
Prior Knowledge	0.79	0.23	0.61**
Working Memory Capacity	0.03	0.47	0.11
LB Scientific Concepts	-0.16	0.34	-0.11
LF Scientific Concepts - Refutation Statements	2.29	0.71	1.72**
R^2	0.51		
Change in R^2	0.27		
Non-refutation Text			
Step 1			
Reading Time	0.52	0.02	0.25
Prior Knowledge	0.39	0.25	0.27
Working Memory Capacity	0.12	0.04	0.56**
R^2	0.32		
Step 2			
Reading Time	1.11	0.85	0.43
Prior Knowledge	0.41	0.26	0.27
Working Memory Capacity	0.11	0.04	0.50*
LB Scientific Concepts	0.57	0.03	0.33
LF Scientific Concepts - Filler Statements	-0.35	0.06	-0.15
R^2	0.34		
Change in R^2	0.02		

Note. LB = Look-back fixation time; LF = Look-from fixation time; * = $p < .05$; ** = $p < .01$.

5.5. Discussion

This fourth and last study was aimed at further advancing our knowledge of the refutation text effect by examining, first of all, how readers with different working memory capacities process the information presented in a refutation text through multiple objective measures of cognitive processing during reading (eye-fixation indices). Specifically, it was examined whether the refutation text may be particularly helpful for readers with lower working memory processing and lower temporary storage of information. Furthermore, it was investigated the co-activation process of alternative and scientific conceptions (Kendeou & van den Broek, 2007; van den Broek & Kendeou, 2008; van den Broek, 2010) in readers who vary for their working memory. Finally, it was studied the link between online text processing and offline learning from text to see whether, and to what extent, co-activation predicts the latter.

The first research question asked whether a refutation text is more effective for readers with a lower verbal working memory capacity than a standard text. As hypothesized, the findings show the superiority of the refutation structure in learning new scientific concepts. Both lower and higher-span refutation-text readers reached the higher learning performance. This expected outcome is in line with most previous studies that have investigated offline products of learning from refutation text with students of different grade levels (e.g., Diakidoy et al., 2003; Hynd, McWhorter, Phares, & Suttles, 2004; Mason et al., 2008). Specifically, the knowledge gains of lower-span readers of the refutation text were greater that those of lower-span non-refutation text readers. This specific evidence leads to the conclusion that the refutation text supports lower-span readers' learning, allowing them to overcome their limitations in the temporary storage of information. A compensation for limited working memory capacity also emerged in previous research that considered other potentially beneficial individual factors, such as having more availing epistemic beliefs about knowledge (Burton & Daneman, 2007).

The second and third research questions concerned online cognitive processing during reading. The second research question asked whether lower- and higher-span readers of the refutation text co-activate the scientific information and their inaccurate conceptions more during reading. Findings about a specific eye-fixation measure of co-activation, the look-from fixation time, revealed that the refutation text better supports the simultaneous processing of inconsistent information. In particular, lower- and higher-span refutation text readers were able to co-activate the inaccurate ideas explicitly stated in the refutation statements and the correct scientific explanations more strongly than higher-span readers of the non-refutation text. No difference emerged between all refutation text readers and the lower-span readers of the non-refutation text. To account for this result, it should be noted that look-from fixations are, together with look-backs, a measure of second-pass reading. Overall, readers with a lower temporary storage of information are expected to make longer second-pass reading fixations on the text, in order to reinstate the information previously read (Kaakinen, Hyönä, & Keenan, 2003). The filler statements included in the standard text provided an overview of the scientific information that non-refutation text readers were about to encounter. In this regard, it is reasonable that lower-span readers of the non-refutation text engaged more in looking back at the filler statements, while reading the parts of the text presenting scientific information, in an attempt to reinstate the previously read information to enhance their comprehension (Hyönä & Lorch, 2004; Lorch & Lorch, 1996; Lorch, Lorch, & Matthews, 1985). This, in turn, resulted in long look-from fixations to the filler statements from the scientific parts, even though these fixations were shorter than those made by refutation-text readers who co-activated more inconsistent information. In sum, although it may not be sufficient, the detection of a conceptual inconsistency can be considered as the basis of a successful process of learning through knowledge revision (Dole & Sinatra, 1998; Limón, 2001; Sinatra & Broughton, in press).

The third research question asked whether a refutation text facilitates the elaboration of text information compared with a non-refutation text, particularly during look-backs (see second and third studies, Chapters 3 and 4). Findings revealed that lower- and higher-span readers of the non-refutation text spent more time during the second-pass reading of the text than refutation text readers. Specifically, the former backtracked the text segments presenting scientific conceptions for longer than higher-span readers of the refutation text. By providing readers with retrieval cues (Ericsson & Kintsch, 1995), refutation statements scaffold them to retrieve the alternative ideas from memory and revise them to learn scientific explanations. This also makes the reading process less difficult to carry out, which accounts for why the refutation-text readers needed to backtrack less in the text than the non-refutation text readers.

Finally, the last research question asked whether online text processing predicted offline learning from text. The outcomes of regression analyses revealed that the eye-fixation process measure of co-activation, the look-from fixation time to the reader's own alternative conceptions while reading the new scientific concepts, predicted only the knowledge gains of the refutation-text readers. New empirical evidence is therefore provided for the hypothesis that simultaneous processing of correct and incorrect knowledge is a mechanism underlying the refutation text effect (van den Broek & Kendeou, 2008). To some extent, this finding also supports the idea that the detection and resolution of a cognitive conflict generated in the reader's conceptual structures is a crucial step in learning through knowledge revision, although it does not occur automatically under instructional conditions (Chinn & Brewer, 1993; Chinn & Malhotra, 2004).

In contrast, only verbal working memory capacity predicted learning from non-refutation text when the indices of visual behavior during reading were entered into the analysis. This confirms a finding in the literature on reading comprehension skills (e.g., Gernsbacher, Varner, & Faust, 1990).

Interestingly, reading time was also a significant negative predictor of learning from the refutation text. This outcome indicates that the quality, rather than the quantity of time *per se* spent on the task, is related to conceptual learning, that is, the way in which the reading time is spent. The importance of how, not how long, a text is read corroborates the findings of the first study (see first study, Chapter 2).

Regarding the regressions performed separately for each level of working memory capacity, it emerged that the learning outcomes of lower-span readers were predicted by text type. This finding corroborates other results regarding offline learning and accounts for the compensation effect of refutation text for limited working memory capacity while learning new information. Previous research has also indicated that instructional material can compensate for limited working memory capacity. For example, the text presentation of various Web pages that preserves text units under headings was related to the comprehension of complex topics by readers with lower working memory capacity (Sanchez & Wiley, 2009).

In sum, this study provides new evidence for the refutation text effect. In particular, its principal added value is that new insights have been provided into online processing during refutation text reading by readers with different levels of working memory capacity. The refutation text effect, reflected in knowledge gains obtained through text reading, is mainly related to the simultaneous activation of incorrect and correct conceptions about the examined phenomenon. Co-activation is a cognitive process that can be observed during refutation text reading and is revealed by a fine-grained measure of eye fixations, the look-from fixation time (Hyönä, Lorch, & Rinck, 2003). The refutation text facilitates the processing of text information particularly during the second-pass reading. Readers with a lower working memory capacity learn more when interacting with this type of text rather than with a standard one.

Chapter 6

General Discussion

The research work presented in this thesis has been conducted following a logical succession for an in-depth investigation of the refutation text effect, as represented by the sequence of the four studies. The first study (Chapter 2) has been conceived as an introductory study. This study particularly dealt with methodological issues pertaining to the use of the eye-tracking in monitoring text processing during reading. Theoretical questions concerning the actual effectiveness of eye-fixation measurement to shed new light on students' conceptual change learning processes was also took into account. Sound results emerged from this first study. Nonetheless, some issues remained unsolved, for example whether the refutation text effect would be a unique or composite cognitive phenomenon and whether the distinct sentence types within the topic structure of the text would be differently processed during refutation text reading.

The second study investigated these research questions and, in the logic of this thesis, its findings can be considered the most recent update of the cognitive model of refutation text effect we worked on in these years (see Figure 3.2., Chapter 3). This study revealed that the refutation effect is not a unique and monolithic cognitive effect; rather, it regards diverse sub-processes that take place with different time courses during reading. Furthermore, the study documented that the different sentence types within the text's topic structure influence the execution of these sub-processes, which do not occur "wherever" in the text but are related to specific types of sentence. Specifically, three main sub-processes have been identified and defined as qualifying the general, refutation text effect. The first is a facilitation effect, which is relatively immediate during text processing (it occurs during the first-pass reinspective fixations, the earlier component of reading that indices comprehension processes) and regards the sentences that introduce new topics in the text (topic-introducing sentences). Facilitation means that refutation text readers spend shorter reinspective fixations on the topic-introducing sentences than while they read the standard, non-refutation text.

The second sub-process regards the sentences that conclude a text topic and summarize the information that has been introduced in it (end sentences). This process is also indexed by reinspective fixations, revealing that it is also an early process. Specifically, reinspective fixations on the end sentences are longer when these are in the refutation text. This has been interpreted as a kind of wrap-up effect occurring at discourse level, which is particularly interesting since it reveals that the refutation text prompts the readers to invest extra resources in extracting the gist of the text.

The last sub-process is of a strategic nature: readers return to the refutation statements while reading the informational parts for longer as compared to the analogous look-backs to the non-refutation statements. This sub-process regards the reading behavior between two text parts (the refutation statement and the informational part) and takes place during the second-pass reading of the text. In sum, to synthesize the impact of the refutation text on readers' reading behavior, it should be said that it supports the readers to extract the global meaning of the information read, it makes them more strategic during reading, and it facilitates the readers to learn the scientific concepts.

The last two studies have investigated the interplay of the refutation text and other variables of interest. Specifically, the repeated reading of a scientific text (third study, Chapter 4) and readers' working memory capacity (fourth study, Chapter 5). The main findings from the third study documented that refutation text readers spend less look-back fixation time in reading the scientific information. In contrast, they backtrack the text for longer during rereading when refutation statements do not accompany textual information, being more strategic than non-refutation text readers. This study thus revealed that the effect produced by the refutation statements continues to prompt the use of strategies while reading even during the repeated exposure to the text, when the refutation parts no longer introduce the scientific ones. The conclusion is that the more effective reading behavior the readers "learn" from the refutation text can be transferred to subsequent readings of the text and, potentially, to other, different texts.

With respect to the fourth study, its main results are threefold. First, the refutation text particularly supports the comprehension of readers with a lower working memory capacity span, as they outperformed the lower-span readers of the non-refutation text. Second, refutation text readers more strongly co-activate the misconceptions and scientific information than readers of the non-refutation text. Finally, the co-activation, as captured by a particular type of eye fixations, the look-froms, only predicts refutation text readers' learning performance. In sum, lower-span readers of the refutation text (and, overall, all refutation text readers) co-activate information from different text regions more strongly during reading; then, their learning scores are higher than those by lower-span readers of the non-refutation text. This higher performance is mainly a product of refutation text readers' simultaneous processing of inaccurate ideas and scientific conceptions. The conclusion is that the refutation text can act as a compensation for the lack of working memory capacity, helping the readers with a lower span to process the textual information more effectively, also making them able to learn better.

So, after identifying the main characteristics that qualify the refutation text effect (first and, particularly, second study), our research concentrated on the relationship between this and other effects (repeated reading and working memory capacity) on students' reading behavior while learning from science text. Noteworthy, several findings consistently emerged across the studies. With this respect, second-pass reading behavior was particularly informative. Readers were more strategic during refutation text processing, looking-back the refutation statements for longer while reading the informational parts (second study). Such a strategic approach to text processing was also found in the third study, which showed that refutation text readers spilled the use of effective strategies over the repeated reading of the text. Moreover, refutation text readers in the fourth study continued to look back the refutation statements while processing the scientific concepts, revealing a stronger co-activation; in addition, their learning performance benefited from this reading behavior. Hence, at the end of this research work, the most distinctive feature of the refutation text - which determines its more effectiveness in promoting a better conceptual learning - may be that this type of text makes the readers more strategic as they process the text.

Nonetheless, some research issues are still open. Two of them are particularly relevant at the end of this thesis: (1) how to correctly interpret the kind of processing indexed by second-pass reading eye-fixation measure of look-backs and (2) how to accurately identify a compelling index of the co-activation of inaccurate ideas and scientific conceptions during reading.

Regarding the first issue, previous research has documented that look-backs are an indicator of comprehension difficulties, launched if the comprehension process does not go well (Rayner, 1998). On the other hand, Hyönä and colleagues (Hyönä, Lorch, & Kaakinen, 2002; Hyönä & Nurminen, 2006) observed that the look-back fixations to the most important segments of the text made are strategic in nature. In sum, an equivalent overt behavior, that is, longer look-backs, could be determined by different cognitive mechanisms.

As concerns the second open issue mentioned above, co-activation appears to be a complex process that comprehends both automatic and strategic components. It must be considered as automatic since it is text-driven (van den Broek & Kendeou, 2008). At the same time, it is strategic because it is the product of the integration of distinct information from the refutation statements and the scientific parts (fourth study, Chapter 6). Therefore, first-pass or second-pass reading measures alone could be unable to properly capture the entire co-activation process. With this regard, an additional step in the time course of text processing, intermediate between first- and second-pass reading, would be necessary.

6.1. Educational Implications

What are the implications of these studies regarding the refutation text effect? The first implication concerns the usefulness of eye-tracking methodology that can be effectively used to trace immediate/automatic and delayed/strategic text processing. The studies have clearly documented that these kinds of processes can be revealed through eye-tracking, which provides indices of cognitive processing at different timings of effects while reading complex materials such as those featuring learning tasks investigated in educational psychology. First-pass and second-pass reading reveal the more automatic and delayed processing, which is useful to increase our understanding of how a particular text type affects the process of reading, or why an individual learner variable like working memory capacity, moderates it.

The second implication regards the strategic behavior and the co-activation of inaccurate ideas and scientific conceptions induced by the refutation text. The evidence emerged from these studies highlights the educational importance of text sentences acting as anchoring points, which are useful for the processing and comprehension of the crucial segments that introduce the new information to be learned. The anchoring points build upon what readers know and believe. Carefully crafted instructional texts should include anchoring points rather than introduce new concepts immediately. In this way, they may support an active processing strategy that facilitates the recognition of cognitive incongruity ("something is wrong") and its solution through knowledge repairing.

In addition, a third implication regards the educationally relevant compensatory effect of the refutation text in relation to working memory capacity. It leads to highlighting that the limitation of this system of the mind architecture - which is essential to reading - could be overcome, at least to some extent, by manipulating the instructional material. We do not claim that all study materials should be proposed in a refutation format; this would not be feasible in practice. However, the type of informational text - especially for learning about particularly counterintuitive scientific concepts - could be appropriately manipulated to increase the likelihood that inconsistencies between the readers' own alternative conceptions and the scientific conceptions are perceived. This may not be enough, but it is an important first step towards learning from text through knowledge revision.

In conclusion, from an educational point of view, these studies indicate that the structure of an expository text for learning disciplinary knowledge plays an essential role. Although not all learning texts can be refutation texts, these may be especially useful when complex phenomena must be understood by changing previous representations.

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Appendix A

Specifications of the Statistical Models (Tables A1-A6)

The full specifications of the fixed effects of the models for each eye-tracking measure (see Tables A1-A3 and Table A4) include estimates of the regression coefficients; 95% highest posterior density intervals (HPDs), which are a Bayesian estimate of the most likely values, very similar to traditional 95% confidence intervals; *p* values estimated by the Monte Carlo Markov chain (MCMC) method, using 10'000 simulations; *p* values obtained with *t*-test for fixed effects, using the difference between the number of observations and the number of fixed effects as the upper bound for the degrees of freedom.

The specifications of the random effects (see Table A5 and Table A6**)** comprise the estimated standard deviation for the random effect of participant among with the estimates based on the MCMC samples HDP intervals, such as the MCMC mean and 95% HPDs (see Pinheiro & Bates, 2000, for a detailed treatment of random effects in mixed-effects models).

Table A1. *Fixed Effects of the Model for the First-pass Progressive Fixation Time on Text's Topic Structure.*

Variable	Estimate	MCMC *M*	HPD95 lower	HPD95 upper	*p*MCMC	*pr*(> |*t*|)
Intercept	10.84	10.84	9.72	11.94	.0001	< .0001
Text Type (Refutation Text)	-0.35	-0.35	-0.86	0.23	.22	.21
Sentence Type (Topic-introducing)	3.44	3.44	2.64	4.18	.0001	< .0001
Sentence Type (Medial)	-6.84	-6.84	-7.60	-6.06	.0001	< .0001
Text Type × Sentence Type (Topic-introducing)	-0.68	-0.68	-1.47	0.10	.09	.09
Text Type × Sentence Type (Medial)	-0.36	-0.36	-1.11	0.43	.35	.36

Note. Estimates are in milliseconds per character; MCMC = Monte Carlo Markov chain; HPD95lower = lower boundary of the 95% highest posterior density interval; HPD95upper = upper boundary of the 95% highest posterior density interval; *p*MCMC = *p* values estimated by the MCMC method using 10'000 simulations; *pr*(> |*t*|) = *p* values obtained with the *t*-test, using the difference between the number of observations and the number of fixed effects as the upper bound for the degrees of freedom.

Table A2. *Fixed Effects of the Model for the First-pass Reinspection Time on Text's Topic Structure.*

Variable	Estimate	MCMC *M*	HPD95 lower	HPD95 upper	*p*MCMC	*pr*(> |*t*|)
Intercept	16.24	16.23	13.89	18.38	.0001	< .0001
Text Type (Refutation Text)	-0.16	-0.15	-1.11	0.82	.758	.744
Sentence Type (Topic-introducing)	-6.79	-6.78	-8.20	-5.53	.0001	< .0001
Sentence Type (Medial)	8.94	8.94	7.58	10.21	.0001	< .0001
Text Type × Sentence Type (Topic-introducing)	-1.95	-1.95	-3.25	-0.57	.005	.004
Text Type × Sentence Type (Medial)	0.76	0.74	-0.59	2.07	0.27	0.26

Note. Estimates are in milliseconds per character; MCMC = Monte Carlo Markov chain; HPD95lower = lower boundary of the 95% highest posterior density interval; HPD95upper = upper boundary of the 95% highest posterior density interval; *p*MCMC = *p* values estimated by the MCMC method using 10'000 simulations; *pr*(> |*t*|) = *p* values obtained with the *t*-test, using the difference between the number of observations and the number of fixed effects as the upper bound for the degrees of freedom.

Table A3. *Fixed Effects of the Model for the Look-back Fixation Time on Text's Topic Structure.*

Variable	Estimate	MCMC *M*	HPD95 lower	HPD95 upper	*p*MCMC	*pr*(> |*t*|)
Intercept	28.45	28.43	24.89	32.02	.0001	< .0001
Text Type (Refutation Text)	-1.47	-1.46	-3.12	0.27	.089	.090
Sentence Type (Topic-introducing)	10.23	10.25	7.84	12.59	.0001	< .0001
Sentence Type (Medial)	-0.09	-0.12	-2.50	2.30	.92	.95
Text Type × Sentence Type (Topic-introducing)	-0.24	-0.24	-2.61	2.23	.850	.842
Text Type × Sentence Type (Medial)	0.67	0.67	-1.65	3.10	.59	.58

Note. Estimates are in milliseconds per character; MCMC = Monte Carlo Markov chain; HPD95lower = lower boundary of the 95% highest posterior density interval; HPD95upper = upper boundary of the 95% highest posterior density interval; *p*MCMC = *p* values estimated by the MCMC method using 10'000 simulations; *pr*(> |*t*|) = *p* values obtained with the *t*-test, using the difference between the number of observations and the number of fixed effects as the upper bound for the degrees of freedom.

Table A4. *Random Effects for the First-pass Progressive Fixation Time, First-Pass Reinspection Time, and Look-back Fixation Time on Text's Topic Structure.*

Estimate	*SD*	MCMC *M*	HPD95lower	HPD95upper
		First-pass Progressive Fixation Time		
Participant	3.24	2.96	2.16	3.82
Residual	8.22			
		First-pass Reinspection Time		
Participant	7.03	6.24	4.73	7.94
Residual	14.11			
		Look-back Fixation Time		
Participant	11.00	9.97	7.40	12.81
Residual	25.41			

Note. Estimates are in milliseconds per character; HPD95lower = lower boundary of the 95% highest posterior density interval; HPD95upper = upper boundary of the 95% highest posterior density interval.

Table A5. *Fixed Effects of the Model for the Look-back Fixation Time on Refutation vs. Non-refutation (Filler) Statements.*

Variable	Estimate	MCMC *M*	HPD95 lower	HPD95 upper	*p*MCMC	*pr*(> |*t*|)
Intercept	20.04	19.97	17.05	22.89	.0001	< .0001
Text Type (Refutation Text)	3.08	3.11	0.83	5.37	.010	.008

Note. Estimates are in milliseconds per character; MCMC = Monte Carlo Markov chain; HPD95lower = lower boundary of the 95% highest posterior density interval; HPD95upper = upper boundary of the 95% highest posterior density interval; *p*MCMC = *p* values estimated by the MCMC method using 10’000 simulations; *pr*(> |*t*|) = *p* values obtained with the *t*-test, using the difference between the number of observations and the number of fixed effects as the upper bound for the degrees of freedom.

Table A6. *Random Effects for the Look-back Fixation Time on Refutation vs. Non-refutation (Filler) Statements.*

Estimate	*SD*	MCMC *M*	HPD95lower	HPD95upper
Participant	7.23	5.35	1.38	9.02
Residual	19.50			

Note. Estimates are in milliseconds per character; HPD95lower = lower boundary of the 95% highest posterior density interval; HPD95upper = upper boundary of the 95% highest posterior density interval.

Appendix B

Specifications of the Statistical Models (Tables B1-B5)

The full specifications of the fixed effects and random effects of the models for each eye-tracking measure (see Tables A1-A5) are identical to the specifications of the models presented in Appendix A.

Table B1. *Fixed Effects of the Model for the First-pass Fixation Time on Topic-Introducing and Topic-Progression Sentences.*

Variable	Estimate	MCMC *M*	HPD95 lower	HPD95 upper	*p*MCMC	*pr*(> |*t*|)
Intercept	3.61	3.60	2.91	4.26	.0004	< .0001
Repeated Reading (2nd)	-0.005	-0.005	-0.05	0.05	.830	.828
Text Type (Refutation Text)	-0.11	-0.11	-0.19	-0.02	.015	.023
Sentence Type (Topic-introducing)	-0.11	-0.11	-0.15	-0.05	.0001	< .0001
Repeated Reading × Text Type	0.004	0.005	-0.05	0.05	.859	.868
Repeated Reading × Sentence Type	0.05	0.05	0.05	0.10	.032	.030
Repeated Reading × Text Type × Sentence Type	-0.02	-0.02	-0.09	0.05	.627	.601

Note. Estimates are on a log scale; 2nd = second reading; MCMC = Monte Carlo Markov chain; HPD95lower = lower boundary of the 95% highest posterior density interval; HPD95upper = upper boundary of the 95% highest posterior density interval; *p*MCMC = *p* values estimated by the MCMC method using 10'000 simulations; *pr*(> |*t*|) = *p* values obtained with the *t*-test, using the difference between the number of observations and the number of fixed effects as the upper bound for the degrees of freedom.

Table B2. *Fixed Effects of the Model for the First-pass Progressive Fixation Time on Topic-Introducing and Topic-Progression Sentences.*

Variable	Estimate	MCMC *M*	HPD95 lower	HPD95 upper	*p*MCMC	*pr*(> |*t*|)
Intercept	3.17	3.17	2.89	3.47	.001	< .0001
Repeated Reading (2nd)	0.01	0.01	-0.03	0.05	.647	.641
Text Type (Refutation Text)	-0.07	-0.07	-0.14	0.01	.098	.145
Sentence Type (Topic-introducing)	0.08	0.08	0.04	0.12	.0001	.0002
Repeated Reading × Text Type	0.02	0.02	-0.02	0.06	.286	.284
Repeated Reading × Sentence Type	-0.02	-0.02	-0.08	0.04	.471	.454
Repeated Reading × Text Type × Sentence Type	-0.20	-0.22	-1.49	1.00	.733	.747

Note. Estimates are on a log scale; 2nd = second reading; MCMC = Monte Carlo Markov chain; HPD95lower = lower boundary of the 95% highest posterior density interval; HPD95upper = upper boundary of the 95% highest posterior density interval; *p*MCMC = *p* values estimated by the MCMC method using 10’000 simulations; *pr*(> |*t*|) = *p* values obtained with the *t*-test, using the difference between the number of observations and the number of fixed effects as the upper bound for the degrees of freedom.

Table B3. *Fixed Effects of the Model for the First-pass Reinspection Time on Topic-Introducing and Topic-Progression Sentences.*

Variable	Estimate	MCMC *M*	HPD95 lower	HPD95 upper	*p*MCMC	*pr*(> |*t*|)
Intercept	2.05	2.05	0.99	2.95	.008	< .0001
Repeated Reading (2nd)	0.008	0.009	-0.09	0.12	.865	.873
Text Type (Refutation Text)	-0.25	-0.25	-0.42	-0.08	.004	.005
Sentence Type (Topic-introducing)	-0.61	-0.61	-0.72	-0.50	.0001	< .0001
Repeated Reading × Text Type	-0.13	-0.13	-1.29	1.16	.850	.840
Repeated Reading × Sentence Type	0.19	0.19	0.07	0.29	.002	.0009
Repeated Reading × Text Type × Sentence Type	-0.11	-0.11	-0.26	0.05	.173	.173

Note. Estimates are on a log scale; 2nd = second reading; MCMC = Monte Carlo Markov chain; HPD95lower = lower boundary of the 95% highest posterior density interval; HPD95upper = upper boundary of the 95% highest posterior density interval; *p*MCMC = *p* values estimated by the MCMC method using 10’000 simulations; *pr*(> |*t*|) = *p* values obtained with the *t*-test, using the difference between the number of observations and the number of fixed effects as the upper bound for the degrees of freedom.

Table B4. *Fixed Effects of the Model for the Look-back Fixation Time on Topic-Introducing and Topic-Progression Sentences.*

Variable	Estimate	MCMC *M*	HPD95 lower	HPD95 upper	*p*MCMC	*pr*(> |*t*|)
Intercept	2.08	2.08	0.62	3.40	.025	< .0001
Repeated Reading (2nd)	-0.14	-0.14	-0.24	-0.02	.020	.013
Text Type (Refutation Text)	-0.09	-0.09	-0.35	0.17	.486	.598
Sentence Type (Topic-introducing)	0.35	0.35	0.25	0.46	.0001	< .0001
Repeated Reading × Text Type	0.21	0.21	0.10	0.32	.0002	.0001
Repeated Reading × Sentence Type	0.05	0.05	-0.06	0.16	.335	.317
Repeated Reading × Text Type × Sentence Type	0.03	0.03	-0.12	0.19	.716	.691

Note. Estimates are on a log scale; 2nd = second reading; MCMC = Monte Carlo Markov chain; HPD95lower = lower boundary of the 95% highest posterior density interval; HPD95upper = upper boundary of the 95% highest posterior density interval; *p*MCMC = *p* values estimated by the MCMC method using 10,000 simulations; *pr*(> |*t*|) = *p* values obtained with the *t*-test, using the difference between the number of observations and the number of fixed effects as the upper bound for the degrees of freedom.

Table B5. *Random Effects for the First-pass, First-pass Progressive, First-pass Reinspection, and Look-back Fixation Time on Topic-Introducing and Topic-Progression Sentences.*

Estimate	*SD*	MCMC *M*	HPD95lower	HPD95upper
		First-pass Fixation Time		
Participant	0.23	0.20	0.14	0.27
Subtopic	0.078	0.346	< 0.0001	1.452
Residual	0.509			
		First-pass Progressive Fixation Time		
Participant	0.24	0.20	0.14	0.26
Subtopic	0.04	0.16	< 0.0001	0.61
Residual	0.43			
		First-pass Reinspection Time		
Participant	0.43	0.38	0.23	0.53
Subtopic	0.22	0.59	< 0.0001	1.84
Residual	1.14			
		Look-back Fixation Time		
Participant	0.95	0.71	0.56	0.87
Subtopic	0.43	0.91	0.15	2.69
Residual	1.12			

Note. Estimates are on a log scale; HPD95lower = lower boundary of the 95% highest posterior density interval; HPD95upper = upper boundary of the 95% highest posterior density interval.

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