Cognitive Critique

IMPROVING READING COMPREHENSION: CONNECTING COGNITIVE SCIENCE AND EDUCATION

PAUL VAN DEN BROEK

Department of Education and Child Studies, Leiden University, The Netherlands

E-MAIL: broekpwvanden@fsw.leidenuniv.nl

CHRISTINE ESPIN

Department of Education and Child Studies, Leiden University, The Netherlands

E-MAIL: espinca@fsw.leidenuniv.nl

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ABSTRACT

The ability to read symbols and construct a coherent, meaningful message from those symbols is widely regarded to be a complex and uniquely human cognitive skill. The study of how people attain meaning from symbols -- i.e., how they comprehend -- can provide a window into the inner workings of the human mind and be a testing ground for theories about human intellectual functioning. There are not just theoretical but also practical reasons for studying comprehension. To function adequately in society it is necessary to read and comprehend. In everyday life there are forms to fill out, in-

formational documents to read, and instructions to follow, and education relies heavily on the transmission of knowledge and skills through written materials. The study of how reading comprehension takes place, of factors that prevent its success, and of procedures for diagnosing and remedying problems, has the potential to significantly influence educational practice.

The aim of this paper is to present an overview of the scientific findings on reading comprehension and, in doing so, (1) to convey the nature and complexity of the cognitive processes that take place during comprehension; (2) to illustrate the variety of methods and technologies used in comprehension research; (3) to describe the effects of those approaches on theoretical directions in the field; (4) to discuss the potential relevance of understanding comprehension processes for educational practice.

The paper is divided into two major sections. In the first section, we review cognitive research on reading comprehension, distinguishing the *product* of comprehension –what is stored in the human mind once one has read and comprehended a text – from the *process* of comprehension –the cognitive activities by which the product is constructed. This first section concludes with a description of initial studies examining the neural basis for the described comprehension processes. The second section focuses on the practical implications of the research for educational practice, identifying the promises and limitations of translating cognitive science research into educational practice.

COGNITIVE PROCESSES INVOLVED IN READING COMPREHENSION

An example illustrates the types of products and processes involved in comprehension of a text. Consider the following text excerpt:

> (1) The sequence is quite simple. First you arrange things into different groups. Of course, one pile may be sufficient depending on how much there is to do. If you have to go somewhere else due to lack of facilities, that is the next step, otherwise you are pretty well set. It is important not to overdo things. That is, it is better to do too few things at once than too many. In the short run this may not seem important but complications can easily arise. A mistake can be expensive as well. At first the

> whole procedure will seem complicated. Soon, however, it will become just another facet of life. It is difficult to foresee any end to the necessity for this task in the immediate future, but then one never can tell. After the procedure is completed one arranges the materials into different groups again. Then they can be put into their appropriate places. Eventually they will be used once more and the whole cycle will then have to be repeated. However, that is part of life (adapted from Bransford & Johnson 1972).

Most readers find the passage difficult to comprehend. Now imagine that the passage is preceded by the title *Doing Laundry*. With the title, most readers find the passage easier to comprehend. Indeed, in their classic experiments, Bransford and Johnson (1972) demonstrated that comprehension and memory for the text suffered considerably when no title was provided.

Consider a second example. Imagine reading the following sentences in the middle of a simple narrative about two protagonists, John and Sarah:

> (2) John dropped the banana peel. Sarah fell on her back.

When readers are asked at the end of reading the entire text to indicate whether the text stated that Sarah slipped on the banana peel, most reply yes, that the text stated that Sarah slipped on the banana peel –even though it did not. The reason for the readers' mistake is that they *infer* a connection between the information in the two sentences.

These examples illustrate the creation of coherence -- that is, identifying meaningful connections between the various pieces of information in a text – a skill that, as will be discussed below, is central to the comprehension of text. In the first example, the title provides a focal point around which the subsequent sentences can be connected; in the second example, the reader introduces crucial background information (people usually do not fall without an explanation, banana peels are believed to be slippery) that allows the construction of coherence.

In the following sections, we examine more closely the psychological properties of coherent representations of text, and the processes involved in the construction of those representations. Although the examples in this paper are drawn primarily from nar-

rative texts, similar processes have been found to take place during reading of expository texts (e.g., Kendeou and van den Broek 2005, 2007).

PRODUCT OF COMPREHENSION: A COHERENT MENTAL REPRESENTATION

An essential component of successful comprehension is the construction of a coherent mental representation of the textual information by the reader (Kintsch and van Dijk 1978; Trabasso et al. 1984; Graesser and Clark 1985; Goldman and Varnhagen 1986; Gernsbacher 1990; Zwaan and Singer 2003). To construct a coherent representation, the reader must interpret the various pieces of information in the text and identify meaningful connections between these elements and between the elements and his/her background knowledge. The resulting representation can be depicted as a nodes, that capture the elements in or related to the text, and connections, that capture the semantic relations. Together, these nodes and their interconnections form a network in the reader's mind. This basic representation is a foundation that is expanded by the reader for specific reading purposes and types of comprehension: thus, the reader uses the representation in performing tasks such as retelling, identifying the theme, applying the knowledge presented in the text, evaluating and aesthetically appreciating the text, and so on.

The elements in the mental representation of a text can be connected via different types of meaningful relations, but two have been found to be particularly important, namely referential and causal relations. Referential and causal relations are found in the comprehension of many different kinds of text. Moreover, they are required for the identification of other types of relations, such as thematic relations, problem-solution relations, and so on. Consider the following sentence pair:

> (3) The lady gave the waiter $100. He returned to give her the change.

Most skilled readers will infer that 'he' and 'she' in the second sentence refer to 'waiter' and 'the lady', respectively, in the first sentence. They will also infer that the waiter returned to give the lady change because she had given him $100 and, moreover, may infer that this happened because the lady had ordered a meal or drink and that the meal or drink cost less than $100. Connecting "he" and "she" to waiter and the lady are examples of referential

connections; inferring the reasons for the waiter to return to the lady and give her change are examples of causal inferences.

The relations in the above example are simple, and empirical evidence shows they are identified with great likelihood and with little effort on the part of most readers (for a review, see van den Broek 1994). Indeed, readers often are not even aware of making these inferences. Other relations are considerably more complex. For example, the background knowledge required to construct a relation might be more extensive. Consider the following sentences:

> (4) The moon exerts gravitational pull on the earth. Thereby it contributes to the development of life on earth.

Most readers have little difficulty identifying the referential relation between 'it' in the second sentence and 'the moon' in the first sentence. They experience much more difficulty, however, identifying the causal relation between the two sentences. This is striking because the text is very 'user-friendly' in that it explicitly signals to the reader that a causal relation exists between the two sentences by using 'thereby.' The difficulty arises because few readers have ready access to background knowledge that would allow them to identify the causal relation. Motivated readers will search their semantic memory (background knowledge) for potential explanation as to how the two events are causally connected (often generating incorrect inferences about the involvement of tides rather than correct inferences about the moon's role in contributing to the electromagnetic field that protects the developing life on earth from lethal cosmic rays).

Relations in full-length texts can be complex for other reasons as well. Unlike the previous examples, relations often require integration of information that is separated by a considerable distance in the text. To fully understand the events at the end of Anna Karenina, for example, it is essential to relate them to the events at the very beginning of the novel, hundreds of pages earlier. Moreover, causal relations often require the coordination of multiple text elements rather than just two, as in the previous examples. As a result, even a short text can involve many interconnections, as illustrated Table 1 and Figure 1. Table 1 presents a short text excerpt from an African folk tale; Figure 1 depicts the relational network for this text, with nodes indicating the idea units numbered in the Table and lines indicating the major causal relations. For a complete network, referential and other types of relations would be included as well. Despite

the fact that the text is composed of only 22 idea units (11 sentences), the relational network is relatively complex, consisting of multiple potential relations between nodes.

Table 1. The story of *Epaminondas* (African folk tale; adapted from Trabasso et al. 1984)

1. Once there was a little boy.
2. He lived in a hot country.
3. One day his mother told him to take some bread to his grandmother.
4. She wanted him to hold it carefully
5. so it wouldn't break into crumbs.
6. The little boy put the bread in a leaf under his arm
7. and carried it to his grandmother's.
8. When he got there
9. the bread had crumbled into tiny pieces.
10. His grandmother told him he was a silly boy
11 and that he should have carried the bread on top of his head
12. so it wouldn't have crumbled.
13. Then she gave him a pat of butter to take back to his mother's house.
14. The little boy wanted to be very careful with the butter
15. so he put it on top of his head
16. and carried it home.
17. The sun was shining hard
18. and when he got home
19. the butter had all melted.
20. His mother told him he was a silly boy
21. and that he should have put the butter in a leaf
22. so it would have gotten home safe and sound.

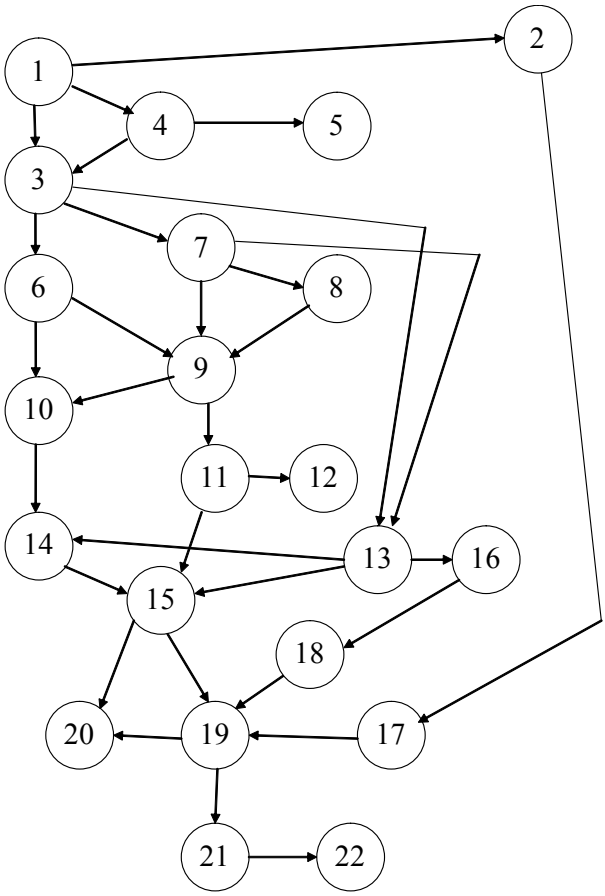

Figure 1. Network representation of the Epaminondas story

The connections provide coherence to the mental representation of the text by the reader. Extensive research in comprehension of narratives and other types of text has shown that texts that elicit a high density of connections on the part of the reader are perceived to be more coherent than texts that elicit a low density of connections. Moreover, individual text elements with many connections are more central to understanding the text than elements with few connections, and are more likely to be remembered by readers (Trabasso and van den Broek 1985; Goldman and Varnhagen 1986; O'Brien and Myers 1987; Fletcher and Bloom 1988; van den Broek 1988). A typical finding is illustrated in Figure 2: The more connections a statement has to other statements, the more likely it is to be

recalled (Trabasso and van den Broek 1985; van den Broek 1994). Similarly, text elements with many connections are judged to be more important to the text by readers and are more often included in summaries than elements with few connections (e.g., Graesser and Clark 1985; van den Broek and Trabasso 1986). As a final example of the evidence for network representations, reminding a reader of a text element primes (i.e., speeds up) the processing of other elements that are connected to the text element, but not of elements that are not directly connected.

In summary, successful comprehension of a text entails the construction of a coherent mental representation of the text. This mental representation consists of a network of semantic relations between text elements and between text elements and the reader's background knowledge.

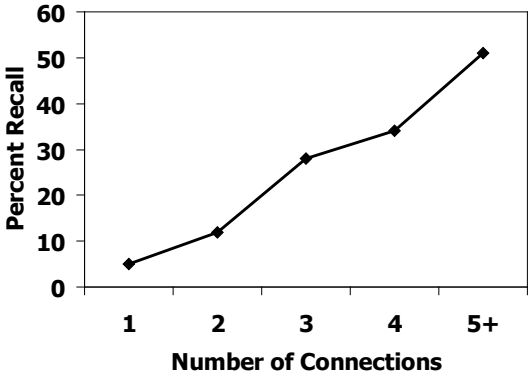

Figure 2. Recall of statements in a text as a function of their number of causal connections to other statements (see Trabasso and van den Broek 1985)

PROCESSES IN COMPREHENSION: BUILDING THE COHERENT MENTAL REPRESENTATION

Identifying semantic relations and building a memory representation while reading pose a challenge for the cognitive system of the reader. To identify a relation between two informational elements, those elements must be activated simultaneously in the focus of the reader's attention. Unfortunately, readers have limited attentional or working memory capacity (e.g., Daneman and Carpenter 1980; Whitney et al. 1991; Just and Carpenter 1992); consequently at any one time the reader can attend only to a subset of all the elements that potentially could be connected. Thus, the reader must balance the need for coherence with the attentional limitations of the human

cognitive processing system. This balancing act has important implications for the reading process.

First, the contents of the reader's attention buffer constantly change as the reader proceeds through the text. New elements become activated, others become deactivated, and yet others increase or decrease in their level of activation. As a result, over the course of reading an entire text, elements fluctuate in their activation, creating a *landscape* of activations (van den Broek et al. 1996; Tzeng et al. 2005). The landscape model of conceptualizing reading comprehension captures not only the on-line process by which reading progresses but also the gradual emergence of an off-line memory representation of the text –as well as the dynamic, reciprocal relation between process and product.

An example is given in Table 2 and Figure 3. Table 2 presents the idea units from a story titled *Knight* (following parsing procedures by Kintsch and van Dijk 1978; and Trabasso et al. 1989). In Figure 3, the landscape model for this story is presented. The major elements of the text are listed along the left axis. Elements from background knowledge are also included in the landscape (Kintsch 1988). Because they tend to be many, and may differ somewhat across individuals, only a few of these background knowledge elements (e.g., 'trees') are included in Figure 3.The axis at the bottom of the figure depicts the reading cycles, with each corresponding to the reading of a clause or major proposition. Finally, the vertical, 'height' axis indicates the level of activation of each text element at a particular point in reading (using a 5-point scale in the example). This landscape captures important aspects of the reading process. Thus, as one 'reads' the figure from left to right the cycle-by-cycle fluctuations in activations can be seen. The cross-section of the figure at a particular cycle indicates which elements are activated simultaneously – and to what degree. By following an individual element across reading cycles, one can trace the course of activation of that element –its 'history' in the reader's processing of the text. For example, the concept "knight" is activated during cycles 1 and 2, and again in cycles 5-12, whereas the concept "horse" is activated only in cycles 1 and 2, and then disappears from activation. It is reasonable that "knight" should be activated more often than "horse": "Knight"' is mentioned more often and is more important to the comprehension of the overall story than is "horse."

Table 2. The *Knight* story

1. A young knight rode through the forest.
2. The knight was unfamiliar with the country.
3. Suddenly, a dragon appeared.
4. The dragon was kidnapping a beautiful princess.
5. The knight wanted to free her.
6. He wanted to marry her.
7. The knight hurried after the dragon.
8. They fought for life and death,
9. Soon, the night's armor was completely scorched.
10. At last, the knight killed the dragon.
11. He freed the princess.
12. The princess was very thankful to the knight.
13. She married the knight.

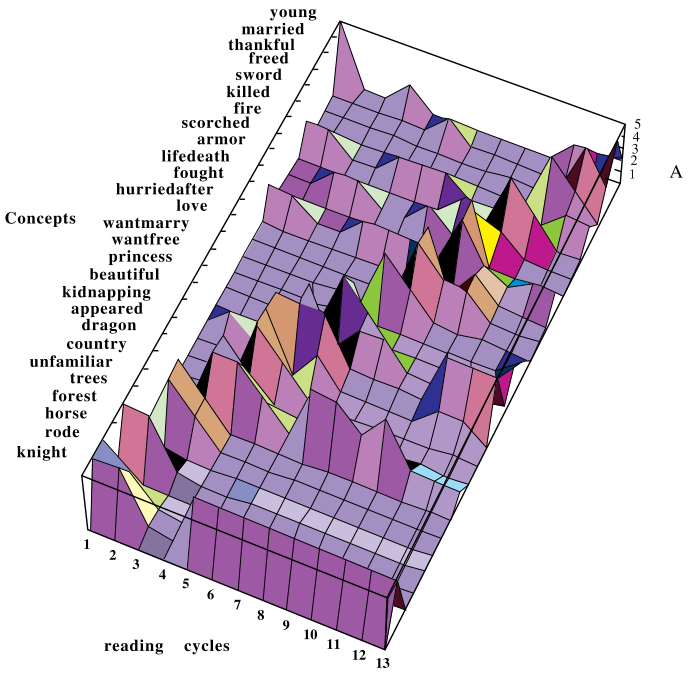

Figure 3. Composite landscape of fluctuating activations during reading of *Knight* story.

Second, because direct connections can only be identified between elements that are simultaneously activated and because attentional capacity is very limited, proper allocation of attention is crucial for comprehension to succeed. Only if the central elements are activated simultaneously can the important connections be identified and incorporated in the developing memory representation. If precious attention is diverted to relatively unimportant elements, comprehension will suffer.

The process of attention allocation is partly outside the control of the reader, partly under his/her control. The part not directly under reader control tends to be fast and automatic, as in examples 2 and 3, and involves memory-based processes such as spread of activation through semantic and episodic memory as well as processes that were once strategic but have become automatized. The part directly under reader control tends to be slow and deliberate, as in example 4, and involves strategic processes. Thus, the reader's strategies (or lack of strategies) for comprehension and attention allocation have a major impact on the attentional patterns which, in turn, directly determine the content and quality of the resulting mental representation of the text.

Fluctuations during reading and individual differences in the ability to allocate attention effectively can be examined via various behavioral methods, for example, computerized speed measurements of experimental subjects' responses to probe words. One common method, *Lexical Decision*, is to have subjects read a text at their own pace on a computer screen. At certain locations in the text (determined by the research hypotheses), the subject sees a string of letters instead of the next sentence, and indicates as quickly as possible (by a button press on the computer key board) whether this string is a word or a non-word. In the preceding banana-fall example (2), the target string might be 'slip.' The speed with which subjects respond to the word "slip" is an indication of the activation of the concept 'slip' in the reader's attentional buffer at that moment. A second, increasingly used method is that of eyetracking, in which a camera records exactly where the reader fixates, i.e., directs attention, in a text. Data from eyetracking methods show clearly that readers do not process a text in a smooth, linear fashion but jump from one location to the next (the jumps are *saccades*, the landing are *fixations*); e.g., Just and Carpenter 1992. Importantly, the location, duration, and sequential patterns of the fixations and saccades reveal a considerable amount about the cognitive process-

es in which the reader engages during reading. Different types of fixations have been found to be relevant to text processing research. *First pass forward fixations* indicate the fixations by a reader the first time he/she passes across the text in a clause or sentence; *First pass rereading fixations* indicate that the reader moves back within a sentence, i.e., rereads parts of the current sentence; *Look back fixations* indicate that the reader moves back outside the current sentence, to an earlier-read part of the text. The first two types of fixations largely reflect within-sentence processing, i.e., pertaining to word identification and grammar, whereas the look back fixations largely reflect strategic efforts by the reader to connect the contents of the current sentence to the content of prior sentences.

Together, the results of the various methods of investigation have shown that readers have an attentional buffer available to process the text they are reading and that this buffer is limited in time and in capacity. Further, the contents of this buffer at a particular time point during reading are determined by the information in the sentence that is currently being read (i.e., the input at that reading cycle) as well as by information that is being activated from the reader's background knowledge and from the prior text. The latter information may be accessed by reinspection of the physical text or by retrieval from episodic memory for the text. The activation from outside the current text and the resulting inference generation may be fast and automatic as in example (2) above or slow, strategic and effortful as in example (4). Consistent with the findings of research on the product of comprehension (described in the section on coherent representations), activations from prior text or background knowledge most often involve efforts to generate causal and referential inferences to create semantic connections for the information in the currently read sentence.

Of theoretical as well as practical importance is the fact that the findings from these methods indicate that there are considerable individual differences in the quality and quantity of coherence-building processes during reading. For instance, school-age readers who are identified as struggling by their scores on standardized tests and by their teachers fall into distinct subgroups with distinct patterns of comprehension processes: some restrict their processing almost entirely to the current sentence and only occasionally venture beyond this sentence to access background knowledge or connect to prior text, others *do* go beyond the current sentence but do so in an

erratic manner, accessing erroneous or irrelevant information (Rapp et al. 2007).

In summary, as readers proceed through a text they have to balance the limitations of their attentional system with the extent to which the mental representation of the text will be coherent. As a result, reading is a dynamic process of fluctuating activations. For good readers, this process includes efficient and effective searching of (memory for) prior text and semantic knowledge for information that may contribute to the perception of coherence. For poor readers -or for good readers when reading texts in an unfamiliar domain- the process may be less than optimal due to of lack of knowledge or motivation, the absence of appropriate strategies, etc. The landscape of fluctuating activations provides the basis for the gradual emergence of a memory representation of the text as a whole, by creating connections between simultaneously activated elements from the text and from background knowledge. Whereas most theoretical models of reading focus on process or product, the Landscape model integrates insights about both the process and the product of reading comprehension.

EXPLORATIONS INTO THE NEURAL FOUNDATION OF TEXT COMPREHENSION

In recent years, forays have been made into the investigation of neural processes involved in reading comprehension. One important tool in such research involves electroencephalography (EEG). In this technique, continuous scalp measurements of electrical activity in the brain are collected. By giving subjects carefully designed texts to read, one can observe changes in the electrical activity as a function of the processes that are unique to the specific texts. These changes, called Event-Related Potentials (ERPs), in turn allow conclusions to be drawn about the specific processes involved in reading of those texts as well as about the timeline of these processes. For example, using ERP techniques it has been possible to determine that, contrary to some existing theoretical models, readers do not wait until they have finished reading a sentence to establish referential connections, but begin doing so as soon as the combination of information in the sentence and the still active information from the preceding context provides sufficient constraints towards a particular connection (van Berkum et al. 2007). Another frequently used technique is that of functional Magnetic Resonance Imaging (fMRI) which allows one to obtain a detailed picture of blood oxy-

genation patterns in the brain and, in turn, of brain structures. As with EEG/ERP, changes in the fMRI signal can be obtained in response to specific tasks, allowing researchers to identify brain regions involved in those tasks. Whereas EEG provides high temporal resolution, MRI allows for accurate localization. The findings with fMRI in the domain of text comprehension suggest that certain regions of the brain (e.g., prefrontal cortex, anterior temporal lobe, and parts of the right hemisphere) tend to be involved in specific components of text processing (Ferstl et al. 2008). For example, when readers encounter global inconsistencies in a text (e.g., a character described at the beginning of a text as vegetarian later orders a hamburger) activation can be seen in the dorsolateral prefrontal cortex –an area associated with executive control processes- and in the precuneus –an area sometimes associated with character identification (van den Broek et al. 2009).

A third technique involves measuring the magnetic changes that occur during processing. This technique, magnetoencephalography (MEG), has strong temporal resolution and allows for analysis of dynamic brain patterns during reading. Preliminary results (Merkle et al. 2007) indicate that dynamic brain patterns change as the reader encounters new textual information, and that these patterns are systematically connected to specific inference-building cognitive activities.

As mentioned, explorations into neural correlates of comprehension processes have begun only recently. As a consequence, interpretation of the results is still tentative and implications for theorizing are broad rather than specific. Yet, this investigation is changing the questions that researchers ask. For instance, neural investigation requires detailed and fairly precise theoretical models of processing. To illustrate, to identify brain regions involved in reading (or any other higher-order cognitive activity) one needs to specify the precise nature of the processes at particular time points. Stating that inference generation takes place during reading is not sufficient: the models must specify exactly which inferential process takes place and at what points during reading. Without such specification, processes are confounded and signals become uninterpretable. Although limited, results of neural investigations also provide conceptual constraints on psychological accounts. For example, the above mentioned findings on the processing of inconsistencies in a text pertained to global inconsistencies –those spanning a distance of multiple sentences. Results on local inconsistencies

–those between adjacent sentences- revealed a different pattern of neural activity, suggesting that the processing of global and local inconsistencies differs and that psychological theories must describe *how* they differ. Neural investigation of reading comprehension processes also has implications for our understanding of brain functionality. Precisely because the models of text comprehension are quite detailed –as exemplified by the Landscape model- reading comprehension research provides a testing ground for neural models of cognitive functioning. By isolating and manipulating specific processes and observing corresponding neural activities, the functions of the involved brain regions can be specified with greater precision.

The integration of neural and cognitive-psychological studies of reading may ultimately have practical implications as well, for example in the context of educational practice. We will turn to this topic below.

COGNITIVE PROCESSES IN READING COMPREHENSION: SUMMARY

Successful reading comprehension depends on the reader's ability to construct a coherent mental representation of the text. Such a representation is constructed from pieces of information that are presented in the text as well as from background knowledge. What holds these individual pieces of information together is the semantic 'glue' provided by causal, referential, and other relations. The construction of such a representation relies on the intricate interplay of cognitive activities, some of which occur outside the reader's awareness (i.e., automatic) others of which are initiated by the reader (i.e., strategic). As the reader proceeds through the text, the interplay changes, yielding different combinations of processes and corresponding changes in the information in the limited attentional buffer at that moment.

The inferential processes reviewed here take place in all reading contexts and across levels of reading -by novices and struggling readers but also by highly trained readers such as academics and other scholars. Moreover, these processes can fail in even the most experienced reader, for example when he or she lacks the background knowledge required to understand a text, or when one's limited attentional capacity interferes with adequate allocation of resources. Consideration of factors that lead to success in compre-

hension and those that cause failure may have important educational implications.

THE PATH FROM BASIC RESEARCH TO APPLICATION

How can we apply what we know about the cognitive processes involved in comprehension to practice? On the surface, the answer seems obvious: If we know the cognitive processes involved in good comprehension, we can teach those processes to children who are learning to read, or we can remediate those processes in children who are having difficulty with reading. However, the path from basic research to application may be less direct than it first appears. In particular, *comprehending* and *learning to comprehend* might involve very different processes.

As discussed in the first section of the paper, readers must build a coherent representation of a text in order to comprehend the text. One important process in building a coherent representation is drawing causal inferences –recognizing the cause and effect relations between events described in the text. Yet, does the ability to make causal inferences *lead to* comprehension or is it a *result of* comprehension? That is, is inference-making an independent variable – a skill to be learned so that comprehension can occur – or is it a dependent variable – an outcome that occurs when other skills have been learned? The answer to this question is essential to instructional application.

To illustrate the complexity of moving from basic to applied research, it is helpful to examine in context the skills necessary to comprehend a text. Consider the sentences below:

> Het was 5 december en buiten was het donker en koud maar binnen brandden de kaarsen en de sfeer was erg gezellig. Ineens werd er geklopt op de deur. Met een gil sprongen de kinderen van hun stoel en renden naar de deur. Maar waar was vader? Weer heeft hij het gemist!

For readers not familiar with the Dutch language, it is likely that comprehension did not occur when reading the preceding sentences. An obvious first step in comprehending text, and a prerequisite step for forming inferences between the events represented in the text, is the decoding of the words and phrases in the text and the connecting of those words and phrases to concepts in the reader's lexicon.

But lack of comprehension may not be caused solely by the reader's inability to read the words in the text. If it were, then transliterating the sentences into English should result in comprehension:

> It was 5 december and outside was it dark and cold but inside burned the candles and the atmosphere was very cozy. Suddenly was there knocked on the door. With a yell jumped the children from their chairs and ran to the door. But where was father? Again has he it missed!

The English-speaking reader can now decode and read the sentences, and can connect the words to concepts in his/her lexicon. However, it still is likely that the reader experiences difficulty reading and understanding the text.

To comprehend the text –to draw inferences between events represented in the text – it is necessary to possess knowledge of the semantics and syntax of the language. The above text is a direct translation of Dutch, a language that is different in semantics and syntax from English. The text differs from English in the placement of the verb (e.g., *Suddenly was there* . . .), word usage (e.g., children *jump from their chair* rather than *jump up from their chairs* and there is *knocked on the door* rather than *a knock at the door*), sentence length (e.g., Dutch allows for longer sentences with more clauses), and use of punctuation (e.g., English would require a comma after the phrase, "With a yell . . ."). Putting the text in a form that is more accurate in terms of English semantics and syntax should improve a reader's ability to understand text and to draw inferences between events represented in the text:

> It was the 5th of December. Outside it was dark and cold, but inside the candles were lit and the atmosphere was cozy. Suddenly, there was a knock at the door. With a shout, the children jumped up from their chairs and ran to the door. But where was Father? He had missed it again!

For most readers the sentences now are easier to read, and inferences necessary to understand the text more easily generated. For example, one can infer that the children were at their home, that it was evening, and that there was something special about the situation –some expectation perhaps even- because the children seemed excited when they heard a knock at the door. But unless the reader is Dutch, or has spent a significant amount of time in the Netherlands, understanding of the passage is still likely to be incomplete; that

is, the inferences needed to build a coherent representation of the information will most likely not have been generated.

To fully comprehend the text, the reader needs background knowledge about the Dutch culture. For example, a Dutch reader would automatically infer that the family had gathered and was having a pleasant evening together because (1) December 5th is a time of family gathering, and (2) the scene is described as *gezellig*. *Gezellig* implies a time of gathering, of coziness, of warmth, of pleasure. (Although the word is translated into *cozy*, there is actually no direct translation of the word into English.) A Dutch reader would further infer that it was Sinterklaas (a Dutch version of Santa Claus) who had supposedly knocked at the door because December 5th is the day Sinterklaas comes to bring gifts to the children. Further, a Dutch reader would infer that the children would find a bag of gifts at the door that had been left behind by Sinterklaas and his helpers. Finally, the question of "Where was Father?" would probably bring a smile to the face of a Dutch adult reader. Father would be the person who had secretly placed the gifts by the front door, knocked, and then immediately ran to the back door to magically appear just as the children were bringing the bag of gifts into the living room. The children would admonish Father for always being too late to hear Sinterklaas knock at the door.

The purpose of the illustration above is twofold. One is to demonstrate the complex nature of drawing inferences from a written text. To make inferences between various parts of a text, a number of skills are needed: decoding the written language and attaching written words to meaningful concepts, knowledge of the semantics and syntax of the language, and background knowledge of the events represented in the text. A second purpose is to demonstrate the complex nature of determining whether inference-making *leads to* comprehension or is the *result of* comprehension. Put differently, once a reader has decoded and read the written words in a text, has knowledge of semantics and syntax of the language, and possesses and activates background knowledge related to the content of the text, has he or she comprehended the text and do inferences follow? Or is inference-making an additional skill that must occur above and beyond the skills just named before comprehension has occurred?

The answer to the question of whether inference-making leads to or is the result of comprehension has important implications for practice. If inference-making *leads to* (or contributes to) compre-

hension, then the way to teach or improve comprehension may be to teach or improve skills and strategies of inference-making. If inference-making is the *result of* comprehension, then the way to teach or improve reading comprehension may be to teach or improve decoding, language knowledge, and background knowledge. To complicate the situation, the answers to these questions may differ from learner to learner.

In summary, the path from basic research to application is not necessarily a direct path. To translate basic research into practice, it is necessary to formulate hypotheses about potential implementation of basic research knowledge into practice, and then to test these hypotheses via applied experimental, controlled studies. The benefit of such translational studies is twofold: To improve educational practice and to further refine our knowledge of the basic processes involved in reading comprehension. Below, we provide an example of the interactive nature of basic and applied research.

EXAMPLE OF TRANSLATIONAL RESEARCH

A consistent finding in the educational literature on reading comprehension is that questioning is an effective technique for improving comprehension of text (see reviews by Mastropieri and Scruggs 1997; Gersten et al. 2001). Questioning has been used in various forms and for various reasons, including activating prior knowledge, summarizing information, monitoring performance, directing attention, promoting active processing of text, and so on. However, little research has been conducted on the most effective form of questioning, the most effective placement of questions, and whether the effectiveness differs for subtypes of struggling comprehenders. The research on the cognitive processes underlying reading comprehension can help to refine and clarify the use of questioning techniques for struggling readers. As mentioned previously, in a study of struggling readers in grades 4, 7, and 9, van den Broek, McMaster, Rapp and colleagues identified two subgroups of struggling readers (see Rapp et al. 2007 for a description of this research). The first subgroup of readers made few if any causal inferences between events presented in the text, but instead tended to restate or paraphrase the information presented in sentences they had just read. The second subgroup of readers made causal inferences, but their inferences were often erroneous or irrelevant with regard to the meaning of the text. These subgroups emerged across grades as well as across years of the study.

A plausible hypothesis emanating from these findings is that the first group of students, the paraphrasers, would benefit from instruction that would encourage them to learn to make connections between information in the text, whereas the second group, the erroneous inference makers, would benefit from instruction focused on increasing language and background knowledge to help them make relevant and correct inferences.

To test these hypotheses, the investigators examined the effects of various types of questions on the comprehension of the struggling readers. The first type of question was a specific causal question, drawing on the to-be-connected events presented in the text and prompting the reader to make a causal inference between those events. Consider the following text: "One day, Dudley, a dolphin, was swimming with his family off the coast of the Caribbean Sea. Suddenly, a storm came up and the ocean got very rough. Although he tried to stay close to his family, they became separated. After some time, the storm was finally over. Dudley looked around. He had lost his family!". For this text a question prompting generation of a causal connection is "How did Dudley lose his family?", with the answer being "a strong storm separated them". The second type of questions is a general question, prompting the student to search for connections, but not tied to specific events in the text (e.g., "Is Dudley's losing his family related to something you read earlier in the text?"). The third type of question is a "who," "what," "where" question prompting the reader to attend closely to the content of the text (e.g., "Who is Dudley?"). Comprehension of the texts was assessed using a combination of recall and answers to comprehension questions. The results revealed an interaction between subgroup and question type, with students in the paraphrase subgroup benefiting most from the general questions and students in the inference group benefiting most from the causal specific questions. Neither group benefited from the "who, what, where" questions.

The brief description of this research program shows the interaction between basic and applied research. First, knowledge of the cognitive processes involved in reading comprehension guided the design of the kind of questions posed to the student. Specifically, students were asked questions that drew their attention to the important connections existing in the text. Moreover, the types of questions that were asked were adapted to subgroups that displayed different patterns of cognitive processes. This adaptation based on cognitive processes was shown to be crucial as each subgroup

benefited more from the intervention specifically designed for that subgroup than for the other interventions –including one frequently used in prior research. Importantly, the two subgroups were indistinguishable on traditional measures of comprehension –it was only by considering the underlying cognitive processes that they were distinguished. Conversely, the results of the applied research refine our understanding of the processes involved in reading comprehension. Reading comprehension is not simply making inferences: It involves knowing that inferences must be drawn and connecting the correct information within the text, and from the text to an existing knowledge base to make correct inferences. Thus, readers must possess proper strategies to combine the various pieces of information in a text with each other and with background knowledge in ways that assist comprehension. Moreover, the application of cognitive theory to the design of interventions in educational context provides a stringent test of the accuracy of the theory: If the interventions had revealed different patterns of results then the validity of the theoretical account would have been called into question.

FROM BASIC RESEARCH TO APPLICATION : SUMMARY

The path from the study of the cognitive processes involved in comprehension to the application of that knowledge to practice is not necessarily a direct path. To translate basic research into practice, it is necessary to conduct applied research in which the implementations suggested by the findings in basic research are experimentally tested. With regard to the cognitive processes involved in reading, application research has just begun. Questions yet to be addressed include: (1) Do students remain in subgroups across different types and levels of text (implying a characteristic internal to the individual) or does subgroup membership change with the material being read (implying a characteristic specific to the nature of the material)? (2) Does improving students' ability to make inferences improve their comprehension? (3) Can the findings on subtypes of poor comprehenders and the differential effects of interventions for those subtypes be replicated across studies and laboratories? (4) Is there neural evidence that would help explain the nature of the difficulties for the subtypes of learners –and that would suggest which difficulties are and are not likely to be open to remediation? (5) If a "difficulty with inference-making" subtype is identified, are the difficulties experienced by these individuals seen only within the context of reading or are they seen within other contexts?

Results of application in "real" situations can help to inform the questions posed and methods used by applied researchers. In addition, the results of applied research can help to inform the questions posed and methods used by basic researchers.

CONCLUDING REMARKS

Our understanding of the cognitive processes that take place during comprehension has grown considerably in the past few decades. As a result, the description of reading comprehension has reached a degree of specificity that allows extension into other areas of research. One such area is that of the neural basis of human intellectual functioning. As the theoretical models based on behavioral research have become more detailed, predictions and hypotheses about brain regions and interactive patterns can be generated and tested. Another area extends in a seemingly different direction, namely that of application in education. Through detailed description of successful comprehension –and of potential causes of failure- cognitive models allow the development of diagnostic tools as well as targeted interventions that may prove both effective and efficient. As the examples in the previous sections illustrate, however, cognitive-psychological studies of text comprehension, neural investigations, and applied research in educational settings can be mutually beneficial.

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