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Individualised strategies for prior knowledge activation

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Individualised strategies for prior knowledge activation

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Voorwoord

In oktober 2005 begon ik aan mijn onderzoeksproject zonder een duidelijk beeld van wat de daaropvolgende jaren zouden brengen. Vier jaar later kijk ik terug op een leuke en ontzettend leerzame periode die ik niet had willen missen. Hierbij wil ik graag een aantal mensen bedanken zonder wiens hulp en steun dit proefschrift nooit afgerond had kunnen worden.

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Sandra Wetzels,
Landgraaf, oktober 2009

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Chapter 1

General introduction

Suppose you are asked to bring to mind everything you know about the human circulatory system. Perhaps, you already know that the brain needs oxygen to be able to function, and that the heart pumps oxygenated blood from the lungs to the brain. Subsequently, you are provided with the information that blood flows from the lungs to the heart through the pulmonary vein, and from the heart to the brain via the aorta. If you try to relate the new information (i.e., pulmonary vein, aorta) to the things you already know (i.e., the heart pumps oxygenated blood from the lungs to the brain), this enables you to integrate the newly provided information into your existing knowledge base, which greatly facilitates learning.

In the past decades, research has consistently provided evidence for the beneficial effects of prior knowledge activation on learning. Here, it is important to emphasise that the *availability* of prior knowledge alone is not sufficient to reach higher learning outcomes. This knowledge should be *activated* and *actively used* in order to establish relationships between the existing knowledge and the new information provided to learners (Mayer, 1979). So, prior knowledge provides learners with a framework in which new information can be actively integrated, facilitating recall and understanding of this information.

If learners activate their prior knowledge, existing knowledge is retrieved from long-term memory and activated in working memory. Because prior knowledge activation takes place in working memory, it is subject to working memory's limited capacity. Learners can hold about seven elements at a time in working memory (Baddeley, 1992; Miller, 1956), and if they are required to process elements in working memory, its capacity is even more severely limited to about three elements (Van Merriënboer & Sweller, 2005). This implies that there are limits to the amount of information that can be simultaneously activated. Learners might be overwhelmed by the process of prior knowledge activation, which hampers the activation process and subsequent learning processes. However, the impact of working memory limitations is mediated by the extent to which the information dealt with has been organised in long-term memory (Sweller, 2005). As expertise develops, increasing amounts of organised information are held in long-term memory that can be brought to working memory as a single entity or element (Ginns, Chandler, & Sweller, 2003; Newell & Simon, 1972). This implies that learners' level of prior knowledge is an important factor mediating the beneficial effects of prior knowledge activation on learning.

A central question guiding the research presented in this dissertation is concerned with how prior knowledge activation can be optimised taking learners' amount of relevant prior knowledge into account. Although rarely used in the context of prior knowledge activation, external representations such as pictures, animations, and notes can be very suitable for prompting prior knowledge activation and reinforcing the activation process. Pictures and animations are expected to be especially suitable to prompt prior knowledge activation in domains in which knowledge and understanding of the structure and functioning of a system are important for learning. Then, activating prior knowledge about spatial relations (i.e., how is this structured or built?) and temporal relations (i.e., how does this function or change over time?) is important for fostering subsequent learning. Pictures and animations both represent these spatial relations, and animations also represent the temporal relations. Therefore, they are considered to be suitable prompts for activating relevant prior knowledge. In addition, externally representing prior knowledge by means of taking notes might reinforce the activation process because it reduces the load imposed on working memory during prior knowledge activation. The written notes work as an external memory. However, learners' prior knowledge might influence the effectiveness of these external representations and therefore, the use of external representations in prior knowledge activation should be aligned to learners' level of prior knowledge.

Overview of the dissertation

The main aim of the studies presented in this dissertation is to investigate how prior knowledge activation can be tailored to learners' level of prior knowledge in order to strengthen the beneficial effects of prior knowledge activation on learning. Chapter 2 presents a theoretical framework for prompting prior knowledge activation and reinforcing the activation process in the science domain. This framework provides more insights in how external representations can possibly be used to support prior knowledge activation. Pictures and animations are assumed to be suitable prompts for activating prior knowledge in the science domain, and note taking by the learner during prior knowledge activation is assumed to reinforce the activation process. However, the effectiveness of the prompting and reinforcing effects of external representations in prior knowledge activation is hypothesised to be mediated by learners' amount of relevant prior knowledge in the domain.

The study described in Chapter 3 investigates the reinforcing effects of note taking on the activation process and subsequent learning for high school students with different levels of prior knowledge of the circulatory system. Retrieval-directed note taking is aimed at facilitating the retrieval of information from long-term memory to working memory during prior knowledge activation. If learners are enabled to take notes during prior knowledge activation, they can externally represent their prior knowledge. This implies that learners do not have to keep all elements active in working memory, an offloading effect, which will reduce the load imposed on working memory with beneficial effects on the activation process and later learning. However, the effectiveness of retrieval-directed note taking is expected to be mediated by learners' amount of prior domain knowledge. More specifically, learners with a low level of prior knowledge might not benefit from note taking during prior knowledge activation because they cannot build a coherent external representation from their limited prior knowledge.

The study presented in Chapter 4 also investigates the effects of retrieval-directed note taking depending on learners' prior knowledge. However, it extends the range of learners' prior knowledge by including both high school students and students from higher education, who have considerably more prior domain knowledge about the circulatory system. Again, retrieval-directed note taking is assumed to reinforce the activation process by reducing the load imposed on working memory. However, it is expected that note taking during prior knowledge activation loses its beneficial offloading effects as prior knowledge increases because then the knowledge held in long-term memory is already well organised and can be easily brought to working memory without overloading it. In addition to investigating the effectiveness of retrieval-directed note taking with increasing prior knowledge, this study also investigates the effects of two different prior knowledge activation strategies, namely, mobilisation and perspective taking. The effectiveness of these activation strategies is also expected to be mediated by learners' prior domain knowledge. More specifically, a bottom-up oriented strategy such as mobilisation is hypothesised to be especially beneficial for learners with low levels of prior knowledge because it enables them to elaborate on and extend their limited knowledge base. However, as prior knowledge increases, a top-down oriented strategy such as perspective taking is hypothesised to become more effective because it enables learners to refine their already elaborated knowledge base.

The study presented in Chapter 5 focuses on the prompting effects of pictures, animations, and verbal-only representations. It is assumed that the effectiveness of these different external representations is mediated by learners' prior domain knowledge. More specifically, as prior knowledge increases, pictures are expected to become more effective prompts for prior knowledge activation than animations. If learners activate their prior knowledge about the functioning of a system, using pictures as prompts is assumed to result in more constructive prior knowledge activation because they require learners to mentally animate them in order to activate their prior knowledge about processes. Learners with lower levels of prior knowledge lack the knowledge to engage in such mental animation processes and therefore, animations are expected to be more suitable prompts for these learners. Moreover, if learners lack the knowledge to comprehend and use pictorial representations as prompts for prior knowledge activation in the first place, verbal-only representations are tentatively hypothesised to be more effective prompts than both pictures and animations.

Finally, Chapter 6 provides an overview of the main findings of the studies presented in this dissertation, and discusses these findings in terms of conclusions and theoretical implications. Furthermore, some limitations of the studies are discussed, practical implications are outlined, and directions for future research are described.

Chapter 2

Use of external representations in science: Prompting and reinforcing prior knowledge activation

Abstract

This chapter outlines a theoretical framework providing insights into the use of rudimentary external representations during prior knowledge activation in the science domain. This framework distinguishes representations that *prompt* (i.e., initiate) prior knowledge activation from representations that *reinforce* (i.e., facilitate) the activation process. Prompts that consist of pictorial representations (e.g., pictures, animations) might be more suitable than verbal representations to activate structural and causal models important for science learning. Furthermore, external representations may reinforce the activation process. There are limits to the amount of information that can be activated simultaneously because of human's limited working memory capacity. Self-constructing representations (i.e., note taking) might offload working memory while activating prior knowledge. It is argued that the strength of the prompting and reinforcing effects of external representations during prior knowledge activation is mediated by learners' level of prior knowledge.

Prior knowledge activation has strong facilitative effects on learning. De Grave, Schmidt, and Boshuizen (2001), for example, prompted students to activate their prior knowledge by means of problem-based discussion. Before studying a text that described the process of blood pressure regulation, medical students collaboratively analysed either a problem of blood pressure regulation or a problem of vision. When formulating hypotheses regarding the blood pressure problem or the vision problem, students relied on their prior knowledge to account for these problems in terms of an underlying process, principle, or mechanism. Students who activated text-relevant prior knowledge about blood pressure regulation recalled more information from the text than students who activated text-irrelevant prior knowledge about vision. Prior knowledge activation – in this case by means of problem-based discussion – functioned as a bridge between prior knowledge and knowledge still to be acquired. Problem-based discussion facilitated the integration of new information into the existing knowledge base resulting in higher recall.

This chapter focuses on the use of rudimentary external representations during prior knowledge activation in the science domain. Research on the use of external representations in prior knowledge activation is still quite limited and therefore, a theoretical framework that provides more insights into the effects of external representations on the process of prior knowledge activation is described. More specifically, it is assumed that external representations (e.g., pictures, animations, notes) can be used to *prompt* (i.e., initiate) prior knowledge activation as well as *reinforce* (i.e., facilitate) the activation process. In addition, these prompting and reinforcing effects of external representations are assumed to be mediated by learners' level of prior knowledge (see Figure 2.1).

The structure of this chapter is as follows. First, the facilitative effects of prior knowledge activation on learning are described. What is prior knowledge activation and how does it facilitate learning? While answering this question, one prior knowledge activation strategy (i.e., mobilisation) is outlined in detail. Second, the use of external representations in prior knowledge activation is explored, addressing the question how prior knowledge activation can be optimised through the use of external representations. Here, the different functions of external representations in prior knowledge activation are outlined. Third, the role of learners' level of prior knowledge on the effects of external representations in prior knowledge activation is explored.

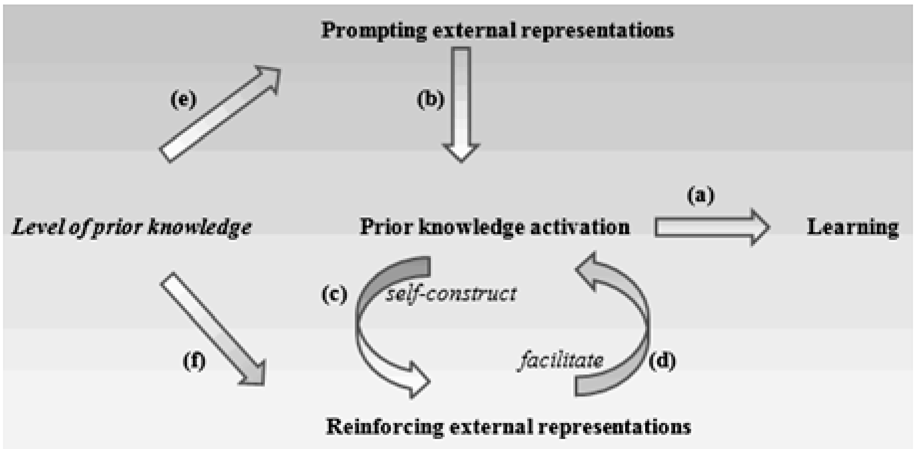


Figure 2.1.
Theoretical framework illustrating the use of rudimentary external representations in prior knowledge activation.

Prior knowledge activation

In line with De Grave et al. (2001), many studies have provided evidence for a strong positive impact of prior knowledge activation on learning (see arrow (a) in Figure 2.1) (e.g., Goetz, Schallert, Reynolds, & Radin, 1983; Ozgungor & Guthrie, 2004; Verkoeijen, Rikers, Augustus, & Schmidt, 2005). According to Mayer (1979, p. 134) learning involves '…relating new, potentially meaningful material to an assimilative context of existing knowledge…'. This implies that it is not sufficient to merely possess prior knowledge. In order to reach higher learning outcomes, the *available* knowledge should be *actively used* during information processing in order to establish relationships between the already available knowledge and new information provided to learners (Ausubel, 1963; Mayer, 1979).

The accuracy and efficiency with which knowledge can be activated and used as a framework for integrating new information is influenced by the way knowledge is represented in memory. Existing knowledge is represented by an associative network of nodes and links (Kintsch, 1988). The nodes represent concepts, which are important units of knowledge. A concept is an idea about a phenomenon or object (e.g., cat, burglar) that is related to other concepts (e.g., animal, crime). The relations between different concepts are represented by the links that connect different nodes. This interconnected pattern of nodes (i.e., network) enables learners to meaningfully organise knowledge contained in these connections. If prior knowledge is activated, specific nodes in the network are activated. Because of the links between nodes, activation can easily spread from a specific node (e.g., heart) to other connected nodes (e.g., blood flow, love). The more often particular links between nodes are used, the stronger these links become. As a result of frequent use, learning takes place through strengthening of connections. In addition, the network provides a framework in which new information can be integrated resulting in new links between nodes. This framework facilitates learning because it offers the opportunity to establish connections between new information and the existing knowledge contained in the pattern of nodes (Anderson, 1983). This bridges the gap between the existing knowledge base and new information that is provided to the learner.

A well-known technique for activating prior knowledge is mobilisation where learners are encouraged to bring to mind all knowledge they have in a certain domain (Peeck, 1982). Machiels-Bongaerts, Schmidt, and Boshuizen (1993) asked students in two experimental groups to mobilise either names of US states or names of US presidents. A control group mobilised names of composers. Subsequently, all students studied a list containing the names of 32 US states and presidents. Time to study the list and individual items on the list was fixed. The experimental groups showed higher recall scores than the control group. This higher recall was entirely caused by enhanced recall of items of the mobilised category (i.e., states or presidents). Especially, items of the mobilised category that were not explicitly mobilised (e.g., less well-known president names such as Coolidge or Polk) benefitted from mobilisation. So, the beneficial effects of mobilisation seemed to spill over to items that were not previously mobilised. During mobilisation, activation from mobilised items spreads to items that were not retrieved but were nevertheless processed to some extent. Because of this spreading activation, non-mobilised items of the mobilised category also benefitted from mobilisation.

In another study, Machiels-Bongaerts, Schmidt, and Boshuizen (1995) encouraged students to mobilise all knowledge they had about the fishery policy of the European Union and its consequences. A control group activated prior knowledge about a neutral topic (i.e., tennis). Subsequently, all students studied a text about the consequences of the EU fishery policy for a fictitious fishery village. The text contained information that matched the activated prior knowledge of the experimental group (e.g., a rise in unemployment) and additional, new information (e.g., an alternative income source) that became important in light of the activated prior knowledge. The experimental group outperformed the control group in recall of information from the text. This higher recall was caused by enhanced recall of information that was explicitly activated plus the new information. By relating the activated prior knowledge to the new information, new links are established, which facilitates the integration of this information into the existing knowledge base.

Until now, researchers have mainly used verbal instructions (e.g., '…bring to mind…') to activate learners' prior knowledge. External representations such as pictures, animations, and notes are rarely used for prior knowledge activation. The next section explores this type of prior knowledge activation.

The use of external representations in prior knowledge activation

Before exploring the use and effectiveness of external representations in prior knowledge activation, several dimensions of external representations (i.e., verbal/pictorial, provided/self-constructed) and their effects on learning are outlined. Then, the different functions of external representations in prior knowledge activation are explored.

Dimensions of external representations

Verbal and pictorial external representations. Although external representations can come in many variants, there are only two basic forms; *verbal* (descriptive) and *pictorial* (depictive) representations. Verbal representations use symbols to represent the subject and are therefore powerful in expressing abstract knowledge. Pictorial representations consist of icons that correspond directly to the subject they represent and have the advantage of being "informationally complete". Because information can be directly inferred, pictorial representations are more useful for drawing inferences (Schnotz, 2005). This implies that the processing of pictorial representations may require less mental effort than the processing of verbal representations (Cox, 1999; Mayer, 2001). Larkin and Simon (1987) explain this by making a distinction between the informational and computational equivalence of external representations. Two representations are informationally equivalent if information that can be inferred from one representation can also be inferred from the other. For example, the manual of a DVD recorder may contain a text and a sequence of pictures that provide users with equivalent information on how to program the recorder. Informational equivalence is a precondition for computational equivalence. Representations are computationally equivalent if inferences that can be easily and quickly drawn from information given in one representation can also be easily and quickly drawn from the information that is explicitly provided in the other. Two representations that are informationally equivalent may, however, differ in their computational equivalence. For example, many users may have experienced that it is easier and quicker to use the pictures when programming the DVD recorder as compared to using the text. In this case, the pictures are more computationally efficient.

Although pictorial representations are often considered to be more computationally efficient than verbal representations, this may depend on the type of information (e.g., conceptual, spatial) that is contained in the representation. Pictorial representations that correspond on a one-to-one basis (i.e., are analogue) to the subject may indeed be more efficient when conveying spatial and temporal relations. Verbal representations that use symbols to represent the subject may be more efficient when conveying information about conceptual relations and logical sequences (Larkin & Simon, 1987; Schnotz, 2005).

Provided and self-constructed external representations. In addition to the verbal-pictorial dimension, external representations can be *provided* to learners or they can be *self-constructed* by the learner. Provided external representations have to be interpreted by learners (Cox, 1999). If learning materials are enriched with familiar external representations, this might facilitate learning because information can be coded both verbally and visually (Mayer, 2001). However, if learners are provided with a representation they are unfamiliar with, they might experience cognitive overload as a result of having to verbally and visually integrate this unfamiliar representation. This may enhance cognitive load, which hampers learning. In these situations, it might be more beneficial for learners to self-construct a representation because learners can use the type of representation they prefer and are familiar with. De Westelinck and Valcke (2005) showed that students who were actively engaged in constructing external representations while studying learning materials scored higher on retention and transfer tests than students who studied the learning materials with provided external representations they were not familiar with.

Self-constructed external representations reveal learners' knowledge and the structure of that knowledge (i.e., its internal representation) by externalising this knowledge through the use of symbols and objects (Lee & Nelson, 2005). Here, a distinction is made between *rudimentary* and *sophisticated* self-constructed representations. Rudimentary self-constructed representations consist of brief notes or simple pictures with few interrelations that primarily function as memory aids. This may reduce the load imposed on working memory and enhance learning. Sophisticated external representations could support learners in elaborating on provided information or a given problem. In addition, they can be used for clarification and elaboration of learners' own conceptual understanding. The process of constructing such a sophisticated external representation and interacting with it fosters learners' understanding and is therefore an important component of learning. This is in line with the active processing assumption (Mayer, 2001) and the focused processing stance (Renkl & Atkinson, 2007), according to which actively building sophisticated external representations might promote organisation and integration processes that foster the development of mental models. This implies that constructing sophisticated external representations may increase cognitive load that is relevant for learning.

A well-known example of self-constructing external representations is taking notes. Note taking research has primarily focused on learning from taking notes while attending a lecture (e.g., Austin, Gilbert Lee, Thibeault, Carr, & Bailey, 2002;

Kiewra, DuBois, Christian, McShane, Meyerhoffer, & Roskelley, 1991) or reading a text (e.g., Kobayashi, 2009; Slotte & Lonka, 1999). The overall effects of note taking on learning are positive (cf., Kiewra, 1985; Kobayashi, 2005); most studies have shown that learners who take notes reach higher learning outcomes than learners who do not take notes (e.g., Barnett, Di Vesta, & Rogozinski, 1981). Externally representing information by means of note taking might support the organisation of information and the establishment of idiosyncratic relations between prior knowledge and the information provided in the lecture or text. This facilitates the comprehension of a lecture or text with beneficial effects on learning (Castelló & Monereo, 2005).

Research on the use of external representations in prior knowledge activation is rather limited. However, external representations might serve important functions in the process of prior knowledge activation; *prompting* prior knowledge activation and *reinforcing* the activation process. The prompting and reinforcing effects of external representations are described in the context of prior knowledge activation in the science domain. Note that in this chapter, the focus is on *rudimentary* external representations for two reasons. First, external representations that are used to prompt prior knowledge activation should activate learners' prior knowledge and not provide information to learners. Second, rudimentary external representations can be constructed by learners regardless of their level of prior knowledge. In contrast, learners need a considerable amount of prior knowledge to construct a sophisticated external representation.

Prompting prior knowledge activation

Rudimentary external representations could be used to *prompt* prior knowledge activation (see arrow (b) in Figure 2.1). Learners could be provided with an external representation and asked to activate their prior knowledge about a specific topic using this representation. In science, it is important that learners understand the organisation and functioning of a domain such as the circulatory system (Chi, de Leeuw, Chiu, & LaVancher, 1994). Pictorial representations, therefore, are assumed to be especially supportive in science learning because they are suitable for activating so-called structural and causal models. Structural models are internal, pictorial models that describe how objects, events, or activities are spatially or temporally related to each other. These models support learners' understanding of how a particular domain is organised. Causal models are internal, pictorial models that focus on how objects, events, or activities affect each other and help to interpret processes, give explanations, and make predictions. In these models, cause and effect relations play an important role, which enables learners to see how a particular domain functions and how changes in one component are related to changes in other components (Van Merriënboer & Kirschner, 2007).

Two well-known examples of pictorial representations are pictures and animations. Pictures are static representations and are especially useful for conveying spatial relations (e.g., the structure of the heart), whereas animations are dynamic representations and especially useful for conveying processes (e.g., the functioning of the heart as a result of electrical activity). Because pictures and animations convey spatial and temporal relations (Tversky, Morrison, & Betrancourt, 2002) and correspond directly to the subject they represent (Schnotz, 2005), they might be more suitable to represent and activate the structural and causal models important for science learning than verbal representations.

Reinforcing prior knowledge activation

Rudimentary external representations might not only prompt prior knowledge activation but may also *reinforce* the activation process. The reinforcing effect of external representations arises if learners are given an opportunity to self-construct a rudimentary representation of their prior knowledge (see arrow (c) in Figure 2.1). When considering the beneficial effects of prior knowledge activation on learning, working memory is an important factor. Learners can hold about seven elements at a time in working memory (Baddeley, 1992; Miller, 1956). When required to simultaneously process elements, the capacity of working memory is even more severely limited; about two to three elements can be related or manipulated at any given time in working memory (Sweller, van Merriënboer, & Paas, 1998). If learners activate their prior knowledge, information is brought from long-term memory to working memory. As a result of the limited capacity of working memory, there are limits to the amount of information (i.e., the number of elements) that can be simultaneously held and processed in working memory (Baddeley, 1992; Miller, 1956). This implies that learners might be overwhelmed by the activation process leading them to experience cognitive overload. If learners are overloaded, there is not enough capacity to activate all elements in the existing knowledge base, which will hamper the activation process.

Cognitive overload might be prevented if learners are given an opportunity to externally represent their prior knowledge by means of taking notes. Note taking enables learners to activate many concepts and to relate these concepts to one another without having to keep all concepts active in working memory. In other words, by writing down what they already know about a certain topic, learners can externally code and store their prior knowledge resulting in a rudimentary external representation. This will facilitate the activation process by reducing the load imposed on working memory during prior knowledge activation (see arrow (d) in Figure 2.1). In addition, learners might be enabled to easily retrieve and hold these concepts in working memory when confronted with new information. If relations are built between the concepts activated during prior knowledge activation and new information provided to learners, new links between nodes can be established. This facilitates the integration of new information into the existing knowledge base with beneficial effects on learning.

Although externally representing prior knowledge by means of taking notes is primarily expected to have a reinforcing effect on the activation process, it may also serve as a prompt for additional prior knowledge activation. By taking notes, new ideas might be triggered in long-term memory because of the spreading of activation to interconnected nodes in the knowledge base (Anderson, 1983). If these ideas are subsequently written down, this may again reinforce the activation process. This implies that the prompting and reinforcing effects of rudimentary external representations might be closely intertwined.

External representations, prior knowledge activation, and level of prior knowledge

In prior knowledge activation, rudimentary external representations might prompt prior knowledge activation and reinforce the activation process. However, learners' level of prior domain knowledge might be an important factor mediating the effectiveness of external representations in prior knowledge activation. First, the effectiveness of pictures, animations, and verbal representations as prompts for prior knowledge activation may be mediated by learners' prior knowledge (see arrow (e) in Figure 2.1). Pictorial representations might be more suitable for prompting prior knowledge activation in the science domain than verbal representations because they represent and activate the structural and causal models important for science learning. However, learners need adequate prior knowledge about pictorial representations in order to understand them and to be able to use them as prompts for prior knowledge activation. A specific prompt is only effective if learners possess the knowledge triggered by the prompt. For learners with limited prior knowledge, pictures and animations might not be useful at all because these learners do not yet possess the structural and causal models that are triggered by the pictorial representations. In this case, learners might benefit most from verbal representations (i.e., simply asking them to activate their prior knowledge about a certain topic) without being provided with pictorial representations that are yet meaningless to them. Learners with higher levels of prior knowledge are assumed to possess structural and causal models, and therefore, using pictures and animations as prompts for prior knowledge activation is assumed to result in more effective prior knowledge activation as compared to using a verbal-only representation.

Second, the reinforcing effect of rudimentary external representations may also be mediated by learners' level of prior knowledge (see arrow (f) in Figure 2.1). Self-constructing a rudimentary external representation during prior knowledge activation by means of taking notes is assumed to reinforce the activation process by reducing the load imposed on working memory while activating prior knowledge. However, it may be more difficult to self-construct a rudimentary external representation if learners have limited prior domain knowledge. For these learners, prior knowledge is not meaningfully organised because their knowledge is not yet represented in an interconnected pattern of nodes (Anderson, 1983). This makes it difficult to externally represent prior knowledge by taking notes because learners cannot distinguish relevant from irrelevant concepts or draw relations between concepts (Anderson, 1977). Therefore, self-constructing a rudimentary external representation is not expected to have beneficial offloading effects on working memory for learners at the low end of the expertise continuum.

Note taking is also not expected to have beneficial effects for learners at the high end of the expertise continuum. At high levels of prior knowledge, increasing amounts of organised information are held in long-term memory that can be brought to and activated in working memory as one single element (Ginns et al., 2003; Newell & Simon, 1972). This implies that working memory is not overloaded by prior knowledge activation. Therefore, self-constructing an external representation during prior knowledge activation is also not expected to be beneficial for learners with high levels of prior knowledge. So, the beneficial offloading effects of note taking are assumed to occur only if learners have prior knowledge that can be externally represented but that has not yet evolved into a coherent organised structure.

In sum, rudimentary external representations are assumed to play different roles in prior knowledge activation; they can be used to prompt prior knowledge activation and to reinforce the activation process. However, the effectiveness of rudimentary external representations for prior knowledge activation is assumed to be mediated by learners' level of prior knowledge.

Discussion

In this chapter, a theoretical framework was outlined that described the effects of rudimentary external representations during prior knowledge activation in the science domain. First, it was described that rudimentary external representations can be used to *prompt* prior knowledge activation. External representations that are used as prompts to activate prior knowledge are *provided* to learners. In addition, these representations are preferably *pictorial* (i.e., pictures and animations); pictorial representations are assumed to be more suitable for representing and prompting structural and causal models that are important for science learning. Second, rudimentary external representations were considered to *reinforce* the activation process. By *self-constructing* a rudimentary external representation of learners' prior knowledge (i.e., taking notes), the load imposed on working memory during prior knowledge activation is reduced. This was expected to facilitate the activation process and consequently, learning. Third, it was outlined that the prompting and reinforcing effects of external representations might be mediated by learners' *level of prior knowledge*. A specific type of external representation can only be effective for prompting prior knowledge activation if learners have the knowledge that is prompted by it. In addition, note taking during prior knowledge activation is assumed to only reinforce the activation process if learners have prior domain knowledge that can be externally represented but that at the same time has not yet evolved into a coherent structure.

The theoretical framework described in this chapter is based on prior knowledge activation in the science domain in which the activation of structural and causal models is important for learning. This implies that the framework, and especially the prompting part of it, might be less applicable for more conceptually oriented domains in which the organisation and the functioning of objects, events, or activities are not essential for learning. Another limitation of the framework is that is does not consider any other learner characteristics than prior knowledge. For example, learners with different levels of prior knowledge may also differ in intelligence, motivation, or interest, which may influence the activation process and learning.

In this chapter, it is argued that self-constructing external representations by means of note taking externalises the internal representations of knowledge. Note taking enables learners to externally code and store their prior knowledge, which reduces the load imposed on working memory. However, for learners with relatively high levels of prior knowledge, note taking may result in an active, constructive process that not only externally represents prior knowledge but also reconstructs this knowledge. If this happens, cognitive load may increase as a result of effortful learning.

Several aspects of the framework presented in this chapter are investigated in the studies reported in this dissertation. The first line of research focused on the influence of learners' level of prior knowledge on the reinforcing effect of self-constructed external representations. When do learners benefit from self-constructing an external representation of their prior knowledge by means of note taking? Is note taking during prior knowledge activation indeed not beneficial for learners at the low end of the expertise continuum? And does note taking become ineffective or perhaps even detrimental for learners at the high end of the expertise continuum? These questions are investigated in the studies presented in Chapters 3 and 4.

A second line of research investigated in Chapter 5 focused on the prompting effect of external representations and how this is influenced by learners' level of prior knowledge. It is interesting to explore whether and under which circumstances pictures and animations are more efficient in prompting prior knowledge activation. Pictures might be more suitable for activating structural models and animations for activating causal models. And how is the effectiveness of pictures, animations, and verbal representations mediated by learners' level of prior knowledge? When investigating the prompting effects of pictures and animations, the possibility that learners learn from the pictorial representations should be considered. Even if rudimentary pictorial representations are used to prompt prior knowledge activation, learners may deduce information from it. This implies that the prompt might provide learners with new knowledge, which may result in learning even though this probably will not exceed the recognition level. The study presented in Chapter 5 may also shed some light on this issue.

In sum, the presented framework provides more insights into how rudimentary external representations can be used to support the process of prior knowledge activation and how this might be mediated by learners' level of prior knowledge. The research presented in this dissertation is based on this framework and may provide support for it.

Chapter 3

The influence of prior knowledge on the retrieval-directed function of note taking in prior knowledge activation

Abstract

This chapter investigates the effects of retrieval-directed note taking (i.e., directed at retrieving information from memory) during prior knowledge activation on performance, mental effort, and mental efficiency depending on learners' level of prior knowledge. Retrieval-directed note taking is expected to facilitate the process of prior knowledge activation by giving learners the opportunity to build an external representation of their prior knowledge. This reduces the load imposed on working memory during prior knowledge activation resulting in beneficial effects on the activation process and subsequent learning. However, taking notes might be less effective in facilitating prior knowledge activation if relevant prior knowledge is limited because learners might then not be able to build a coherent external representation of their prior knowledge. Results show that retrieval-directed note taking lowers mental effort and increases mental efficiency for learners with relatively high prior domain knowledge. For learners with relatively low prior knowledge, note taking has the opposite effect on mental effort and mental efficiency.

Prior knowledge activation has a strong positive impact on learning. Schmidt (1982), for example, activated students' prior knowledge by means of problem analysis. Students were asked to explain the problem of osmosis (i.e., swelling and shrinking of a red blood cell in pure water and a salt solution) in terms of an underlying process, principle, or mechanism. When formulating hypotheses regarding the problem of osmosis, students relied on their prior knowledge to account for the observed phenomena. Students who activated prior knowledge showed superior recall and transfer as compared to students who did not activate prior knowledge. Prior knowledge activation – in this case by means of problem analysis – functioned as a bridge between existing prior knowledge and knowledge still to be acquired. This facilitated the integration of new knowledge into already existing knowledge structures resulting in higher recall and better understanding of new information.

In this chapter, the effects of note taking during prior knowledge activation are studied. More specifically, it is investigated if and how note taking during prior knowledge activation influences the activation process and learning taking learners' level of prior knowledge into account. The structure of the introduction of this chapter is as follows. First, the facilitative effects of prior knowledge activation on learning are described. Second, traditional note taking research is shortly described and the differences with note taking as operationalised in this chapter are emphasised. Finally, it is hypothesised how note taking during prior knowledge activation may facilitate the activation process and learning, and how the effects of note taking are mediated by learners' level of prior knowledge.

Prior knowledge activation

In line with Schmidt (1982), many studies have provided evidence for the facilitative effects of prior knowledge activation on learning (e.g., Chi et al., 1994; De Grave et al., 2001; Goetz et al., 1983; Machiels-Bongaerts et al., 1995). Prior knowledge activation involves the transfer of available knowledge from long-term memory to working memory. If new, potentially meaningful information is related to the assimilative context of existing knowledge held in working memory, this information can be integrated in the existing knowledge base. This results in the elaboration and refinement of the existing knowledge base, with beneficial effects on recall and understanding (Mayer, 1979). So, the *availability* of prior knowledge is not sufficient to achieve higher learning outcomes. This knowledge should be retrieved and *activated* in order to establish relationships between existing knowledge and new information.

The way in which knowledge is represented in memory influences how easily, accurately, and efficiently knowledge can be retrieved and activated. Important units of knowledge are concepts. A concept is an idea about an object or phenomenon (e.g., apple, justice) that is related to other concepts (e.g., fruit, jail). According to network models, concepts are stored as nodes with links between nodes representing relations between concepts. This interconnected pattern of nodes enables learners to meaningfully organise knowledge contained in the connections among the various nodes. If prior knowledge is activated, specific nodes in the network are activated. This activation can easily spread to other connected nodes. The more often particular links between nodes are used, the stronger these links become. As a result of frequent use, learning takes place through strengthening of connections. In addition, the network provides a framework in which new information can be integrated. This framework facilitates learning because it offers the opportunity to establish connections between new information and previous experiences (i.e., nodes). The richer the integrated framework, the higher the chance that new information can be connected to already existing knowledge enhancing both recall and transfer of knowledge (Anderson, 1983).

Prior knowledge activation strategies

There are different strategies that can be used to activate learners' prior knowledge. Problem analysis, for example, is a strategy in which learners' collaboratively activate their prior knowledge when constructing explanations for a presented problem (e.g., De Grave et al., 2001; Schmidt, 1982). This is comparable to self-explanation in which learners generate explanations to themselves using their prior knowledge (Chi et al., 1994). Another strategy that is frequently used in prior knowledge activation is mobilisation where learners are explicitly encouraged to bring to mind all knowledge they have in a certain domain (Peeck, 1982). Mobilisation is considered a bottom-up strategy; it serves a broad stage-setting function that provides learners with a relevant context in which new information can be integrated (Peeck, van den Bosch, & Kreupeling, 1982). Because of this bottom-up, stage-setting function, mobilisation is a useful strategy for learners regardless of their level of prior knowledge.

Machiels-Bongaerts et al. (1995) asked students to mobilise all knowledge they had about the fishery policy of the European Union and its consequences. A control group activated prior knowledge about a neutral topic. Subsequently, all students studied a text describing the effects of the restrictive EU fishery policy on a small imaginary fishermen's village. The text contained information about the background of the fishery policy and its consequences (e.g., a rise in unemployment) that were expected to correspond to the activated prior knowledge of the experimental group. Furthermore, the text contained new information (e.g., an alternative income source) that became important in light of the activated prior knowledge. The experimental group outperformed the control group in recall of information from the text. This higher recall was caused by enhanced recall of both the information that was explicitly activated and the newly presented information. By establishing relations between the activated prior knowledge and the new information, the integration of the new information into the existing knowledge base is facilitated. So, mobilisation enables learners to bridge the gap between their prior knowledge and new information provided to them.

Before outlining the potentially beneficial role of note taking in prior knowledge activation, the next section describes the focus of traditional note taking research and emphasises the differences with note taking as operationalised in this chapter.

Note taking

In traditional note taking research, note taking is mainly perceived as a data collection procedure aimed at encoding and storing information for examination purposes. Research focused primarily on learning from taking notes while attending a lecture (e.g., Austin et al., 2002; Kiewra et al., 1991) or reading a text (e.g., Kobayashi, 2009; Slotte & Lonka, 1999). The *encoding* function of note taking signifies that the process of taking notes while attending a lecture or reading a text is beneficial for learning (Di Vesta & Gray, 1972). This effect is determined by comparing learning outcomes (e.g., recall, academic achievement) of learners who were allowed to take (but not review) notes while acquiring new knowledge with learning outcomes of learners who were not allowed to take notes. So, the encoding effect represents the effects of note taking *during* learning. Most studies have shown that learners who take notes reach higher learning outcomes than learners who do not take notes (e.g., Barnett et al., 1981). Note taking can be used to organise information and establish personally relevant relations, which make a lecture or text more comprehensible facilitating learning.

Overall, the encoding effect of note taking is supported (cf., Kiewra, 1985; Kobayashi, 2005). However, some studies could not support the notion that taking notes is beneficial for learning. For example, Peper and Mayer (1978, 1986), and Kobayashi (2009) found that taking notes did not result in higher performance than not taking notes. These inconsistent findings may be related to the quality of the note taking procedures. According to Peper and Mayer (1978, 1986), note taking enhances learning if learners actively process the learning materials and relate it to their prior knowledge. However, learners often take notes that represent a verbatim account of the learning materials in which no personally relevant relations are established. In these situations, note takers may not outperform learners who did note take notes.

In addition to the encoding function, note taking has traditionally been assigned an *external storage* function that indicates that having notes available for review after attending a lecture or reading a text is beneficial for learning (Di Vesta & Gray, 1972). The external storage function is determined by comparing learning outcomes of learners who reviewed their notes with learning outcomes of learners who did not review their notes. So, the external storage function represents the effects of note taking *after* learning. Overall, the external storage function of note taking is supported. Kiewra (1985) analysed 22 studies of which 17 studies supported the external storage function; learners who reviewed their notes reached higher learning outcomes than learners who did not review their notes.

In this chapter, the effects of note taking are investigated in a context that differs from traditional note taking research in several respects. First, the effects of note taking are not investigated in the context of learning from a lecture or a text but in the context of prior knowledge activation. More specifically, it is investigated if and how note taking may support the activation process and subsequent learning. Second, note taking is not assumed to serve an encoding or external storage function. Prior knowledge is already encoded in long-term memory and therefore, note taking has no encoding function. In addition, learners are not given an opportunity to review their notes, so note taking also does not have an external storage function. In this chapter, note taking only serves a *retrieval-directed* function. By means of taking notes, the retrieval of information from long-term memory to working memory is facilitated. Third, traditional note taking research studied the effects of note taking during and/or after learning. In contrast, in this chapter, the effects of note taking *before* learning are investigated. Learners take notes to externally represent their prior knowledge before they are provided with learning materials.

The retrieval-directed function of note taking

How can note taking be used to support retrieval during prior knowledge activation? When considering the effects of prior knowledge activation, working memory is an important factor. Learners can hold about seven elements at a time in working memory (Baddeley, 1992; Miller, 1956). When required to simultaneously process elements, the capacity of working memory is even more severely limited to about three elements (Van Merriënboer & Sweller, 2005). This implies that there are limits to the amount of information (i.e., the number of nodes) that can be simultaneously activated and processed. Learners might be overwhelmed by the activation process leading them to experience cognitive overload. If learners are overloaded, the activation process will be hampered because there is not enough capacity to activate all elements in the existing knowledge base.

Cognitive overload might be prevented if learners build an external representation of their prior knowledge by means of taking notes. When note taking is used this way, it serves a retrieval-directed function because, aided by the notes, learners can retrieve and thus activate more concepts than they could do without the notes. In addition, learners can relate concepts to one another and thereby create an organising framework of their prior knowledge without having to keep all concepts active in working memory. This facilitates the activation process by reducing the load imposed on working memory during prior knowledge activation. When confronted with new materials, learners can hold the (re)organised framework in working memory and use it to integrate new material into the framework, which facilitates learning.

The retrieval-directed function of note taking is expected to facilitate the process of prior knowledge activation by reducing the load imposed on working memory. However, the supporting effects of note taking might be mediated by learners' level of prior knowledge. Taking notes is assumed to be less effective if learners have only limited relevant prior knowledge in a domain (i.e., material is unfamiliar). For these learners, prior knowledge is not meaningfully organised because their knowledge is not yet represented in an interconnected pattern of nodes (Anderson, 1983). This makes it difficult for them to build a coherent external representation by taking notes because they cannot distinguish relevant from irrelevant concepts or draw relations between concepts (Anderson, 1977). Therefore, note taking is not expected to have beneficial offloading effects on working memory for learners who have only limited prior knowledge in a certain domain.

In sum, the main goal of the study presented in this chapter is to investigate the effects of retrieval-directed note taking in prior knowledge activation for learners with different levels of prior knowledge. It is hypothesised that the effectiveness of note taking is mediated by the amount of prior knowledge learners already possess in a certain domain (i.e., biology). Learners with relatively high prior knowledge are expected to benefit from retrieval-directed note taking because externally representing their prior knowledge by means of taking notes will reduce the load imposed on working memory. This facilitates the activation process and thereby, learning. In contrast, retrieval-directed note taking is not expected to have any positive effects for learners with relatively low prior knowledge. These learners are not able to build a coherent external representation of their prior knowledge, and will therefore not benefit from the potentially beneficial offloading effects of taking notes on working memory.

Method

Participants

Sixty-one students in eleventh grade (34 males and 27 females; mean age = 17.07 years, *SD* = .75) participated in the study that was carried out to investigate the hypotheses outlined earlier. To guarantee differences in level of prior knowledge concerning the circulatory system, students with and without biology in their final exams were asked to participate. A 2 x 2 factorial design was used to investigate the retrieval-directed function of note taking depending on learners' level of prior knowledge. All participants completed a prior knowledge test about the circulatory system (see 'Materials'). The maximum score was 12 (M = 5.77, SD = 3.08). Participants were assigned to a low prior knowledge or a high prior knowledge group based on the median score (value '5') of the prior knowledge test. Participants who scored below or at the median were assigned to the low prior knowledge group (n = 37) and participants who scored above the median were assigned to the high prior knowledge group (n = 24). Thus, the terms 'low prior knowledge' and 'high prior knowledge' were used in a relative sense. To test if the two prior knowledge groups differed in their level of prior knowledge concerning the circulatory system, a *t*-test was carried out. The low prior knowledge group (M = 3.65, SD = 1.21) scored significantly lower on the prior knowledge test than the high prior knowledge group (M = 9.04, SD = 2.03), $t(33.61) = -11.730$, $p < .001$, Cohen's d = 3.23. Subsequently, participants were randomly assigned to two note taking conditions resulting in the following four experimental conditions: low prior knowledge/no-note taking (n = 17), low prior knowledge/note taking (n = 20), high prior knowledge/no-note taking (n = 13), and high prior knowledge/note taking (n = 11).

Materials

Prior knowledge test. The prior knowledge test about the circulatory system was a paper-and-pencil test administered to ascertain differences in level of prior knowledge and assign participants to the low prior knowledge or the high prior knowledge group. It contained 12 multiple-choice questions with four answer options that measured knowledge and understanding of the circulatory system. Six questions assessed participants' prior knowledge of the structure of the circulatory system (e.g., Through which blood vessels does blood flow from the leg to the heart?) and six questions assessed knowledge of the functioning of the heart (e.g., What is the function of the heart valves?). One point was given for each correctly answered question on the prior knowledge test resulting in a maximum score of 12. Reliability of the prior knowledge test was α = .77 (Cronbach's alpha).

Prior knowledge activation pictures. To initiate prior knowledge activation, pictures illustrating the structure of the circulatory system and the functioning of the heart were presented. The picture used to activate participants' prior knowledge about the structure of the circulatory system is presented in Figure 3.1.

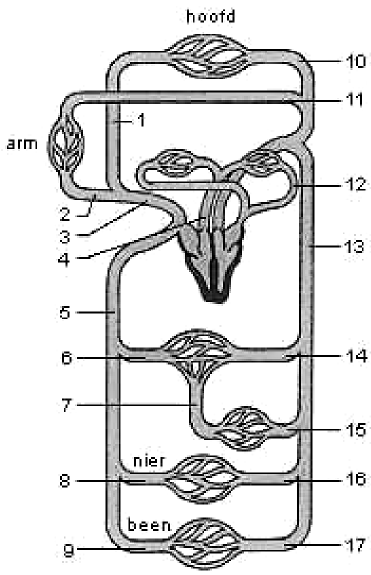


Figure 3.1.
Picture used to activate prior knowledge about the structure of the circulatory system.

Learning tasks. Twelve learning tasks, designed according to the principles of the four-component instructional design model (Van Merriënboer & Kirschner, 2007), were presented in the learning phase. These learning tasks were organised in two sequences of six tasks with one sequence focusing on the structure of the circulatory system and the other sequence on the functioning of the heart. A sequence of learning tasks started with a worked-out example that contained the main principles necessary to solve the problems in the task sequence. For example, the worked-out example in the task sequence about the structure of the circulatory system described in detail how blood flows through the body. After the worked-out example with high built-in support, three tasks with diminishing learner support were presented. Learner support was provided by using so-called reversal and completion problems. In a reversal problem, the correct solution was already given encouraging backward reasoning of why this solution fitted the problem posed. In addition, two types of completion problems were used. In the first type, part of the solution was given and had to be completed by the participants to solve the problem. In the second type, all solution steps were given in a random order and had to be rearranged to solve the problem. These two types of completion problems and the correct solution are illustrated in the Appendix. The last tasks in the sequence were two conventional problems (i.e., no solution steps or correct solutions were provided).

Transfer test tasks. Twelve transfer tasks assessed participants' knowledge and understanding of both the structure of the circulatory system and the functioning of the heart. They differed from each other on a continuum from near to far transfer. For near transfer tasks, learned principles were applied in familiar situations. The underlying structure did not differ from the structure of learning tasks but these tasks contained different surface features, which were irrelevant for solving the tasks. For example, participants were asked to describe how a blood cloth originating in the brain could get stuck in a leg. For far transfer tasks, learned principles had to be applied in new, unfamiliar situations. The structural features of these tasks were more or less different from those of the learning tasks. For example, participants were presented with a problem concerning a child with a congenital heart defect in which the left ventricle was underdeveloped. After an operation, the vena cava were directly connected to the pulmonary arteries and the aorta was connected to the right ventricle. When describing how blood flows from the liver to the brain, participants had to take the child's abnormal blood flow into account.

Scoring

Time-on-task. Time to solve a task was automatically recorded for each learning task and transfer task.

Mental effort. Mental effort was measured using the mental effort rating scale of Paas (1992). This measure was used to assess how much mental effort participants had to invest to complete the prior knowledge test, activate their prior knowledge, and solve each learning and transfer task. Mental effort was rated on a 9-point scale ranging from '*very, very little effort*' (1) to '*very, very much effort*' (9).

Performance. For each learning task and transfer task, partial credits were given for a correct solution step or answer leading to a maximum score of 1 for each task.

Mental efficiency. Efficiency (E) was calculated by relating transfer test performance and invested mental effort during the transfer test using the formula of Paas and van Merriënboer (1993). Performance and mental effort scores were first standardised, and then the *z*-scores were entered into the formula:

$$E = \frac{Z_{Performance} - Z_{Mental\,effort}}{\sqrt{2}}$$

High efficiency indicated a transfer test performance that was higher than might be expected on the basis of invested mental effort during the transfer test, while a low efficiency indicated a transfer test performance that was lower than might be expected on the basis of invested mental effort. For example, two instructional procedures may yield the same performance level with different amounts of invested mental effort. The most efficient instructional procedure is the one that yields the performance level with the least amount of invested mental effort.

Activated knowledge. Activated knowledge was measured by analysing the notes taken by the note taking groups and think-aloud protocols recorded in a randomly selected subset (n = 22) of all participants. The protocols were registered using Audacity version 1.2.6 (http://audacity.sourceforge.net) and a headset. These protocols provided information on the knowledge that was actually activated by the learners. For determining correctness and relevancy of activated prior knowledge, notes and think-aloud protocols were scored according to a coding scheme that contained all important concepts necessary for solving learning tasks and transfer tasks. The worked-out examples were used to distinguish these important concepts (e.g., left ventricle, sinus node) and relations between these concepts (e.g., blood flows from the right ventricle to the lung artery, electrical activity spreads from the sinus node to the atrioventricular node). Two independent raters scored both the number of concepts, the number of relations between these concepts, and the number of correct relations using the coding scheme. Interrater reliability was r = .99 (intraclass correlation).

Procedure

To avoid potential interference with prior knowledge activation, the prior knowledge test was administered more than five days before the experiment. In the experimental session, prior knowledge was activated through mobilisation initiated by the prior knowledge activation pictures. First, the picture of the structure of the circulatory system was presented on a computer screen for 5 minutes and all participants were given the following instructions: "*…bring to mind everything you know about the way blood flows through the body…*" Think-aloud protocols were recorded for a subset of all participants. During mobilisation, all participants were also given this picture on a piece of paper. Only participants in the note taking conditions were instructed to take notes while mobilising using the paper version of the picture. Participants in the no-note taking conditions were not given an instruction to take notes. It was closely observed whether participants followed the note taking instructions. Second, after mobilisation, all participants were asked to hand in the paper version of the picture to prevent participants in the note taking conditions from using their notes while working on the tasks. Then, all participants studied the worked-out example about the structure of the circulatory system and performed the remaining learning tasks concerning this aspect of the circulatory system.

After mobilising prior knowledge and working on tasks about the structure of the circulatory system, participants started working on the sequence of tasks about the functioning of the heart. This sequence zoomed in on a particular aspect of the circulatory system and required more elaborated knowledge than the preceding task sequence about the structure of the circulatory system. Therefore, prior knowledge was again mobilised before participants worked on these tasks. Participants were provided with the picture illustrating the functioning of the heart and were instructed to "…*bring to mind everything you know about the electrical system and the functioning of the heart*…". Again, all participants were given a paper version of the picture. Participants in the note taking conditions were instructed to take notes while mobilising using the paper version of the picture. After mobilisation, participants were again asked to hand in this paper version. Then, participants studied the worked-out example about the functioning of the heart and performed the remaining learning tasks concerning this aspect of the circulatory system.

After all learning tasks were performed, transfer tasks were presented. Participants in the note taking conditions were not allowed to review or otherwise use their notes while working on the learning tasks and transfer tasks. All participants were also instructed not to take notes while performing the learning tasks and transfer tasks.

Participants rated the amount of mental effort they had to invest (a) after completing the prior knowledge test, (b) after mobilising prior knowledge about the structure of the circulatory system, (c) after mobilising prior knowledge about the functioning of the heart, (d) after each learning task, and (e) after each transfer task. All tasks and mental effort scales were presented on the computer screen. Participants were allowed to work on the learning and transfer tasks at their own pace.

Results

Time-on-task

For all statistical tests, a significance level of .05 was maintained. Table 3.1 provides an overview of the means and standard deviations for time-on-task and the dependent variables mental effort, performance, and mental efficiency.

To control for potentially confounding effects of time-on-task, time to perform learning and transfer tasks was explored first. A main effect of prior knowledge on time-on-task was found for the learning phase ($F(1, 58) = 6.939$, $MSE = 9205.372$, $p < .05$, $\eta^2_p = .107$) and the transfer phase ($F(1, 58) = 8.324$, $MSE = 5078.609$, $p < .01$,

η^2_p = .126). The high prior knowledge group spent more time working on learning and transfer tasks than the low prior knowledge group (see Table 3.1). No other main effects or interaction effects on time-on-task were found.

For subsequent analyses, data were analysed by means of 2 (low prior knowledge vs. high prior knowledge) by 2 (no-note taking vs. note taking) ANCOVAs with time-on-task as a covariate. For analysing learning task results, time-on-task during the learning phase was used as a covariate. For analysing transfer task results, both time-on-task during the learning phase and time-on-task during the transfer phase were used as covariates.

Table 3.1
Means and standard deviations for time-on-task, mental effort, performance, and mental efficiency

	Low prior knowledge				High prior knowledge			
	No-notes		Notes		No-notes		Notes	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Time-on-task learning phase (sec.)	111	44	111	23	123	39	150	38
Time-on-task transfer phase (sec.)	81	24	89	17	97	33	111	27
Mental effort learning phase	5.79	1.16	6.28	1.29	5.02	1.49	4.42	1.11
Mental effort transfer phase	5.61	1.49	6.59	1.26	5.42	1.30	4.65	1.28
Performance learning phase	3.95	1.99	4.14	2.16	6.04	1.86	7.32	1.65
Performance transfer phase	3.49	1.43	3.85	1.50	5.61	1.78	6.60	1.60
Mental efficiency	–.29	.90	–.62	.90	.56	1.10	1.27	.85

Mental effort

An interaction effect between level of prior knowledge and note taking was found on mental effort invested during the transfer phase (F(1, 55) = 6.688, MSE = 12.149, p < .05, η^2_p = .108). For high prior knowledge learners, note taking yielded a decrease in mental effort invested while working on transfer tasks, whereas note taking yielded the opposite effect on mental effort for low prior knowledge learners (see Figure 3.2). Post-hoc analyses revealed that mental effort of note takers was influenced by their level of prior knowledge. More specifically, mental effort of note takers with low prior knowledge was higher than mental effort of note takers with high prior knowledge (F(1, 55) = 13.662, MSE = 24.818, p < .01, η^2_p = .199). Moreover, note taking increased mental effort for low prior knowledge learners as compared to low prior knowledge learners who did not take notes (F(1, 55) = 5.367, MSE = 9.751, p < .05, η^2_p = .089).

In addition to the interaction effect between level of prior knowledge and note taking, a main effect of prior knowledge was found on mental effort invested during the learning phase (F(1, 57) = 12.170, MSE = 20.572, p < .01, η^2_p = .176) and the transfer phase (F(1, 55) = 7.945, MSE = 14.433, p < .01, η^2_p = .126). The high prior knowledge group invested less mental effort while working on learning tasks and transfer tasks than the low prior knowledge group (see Table 3.1). No other significant effects were found on mental effort.

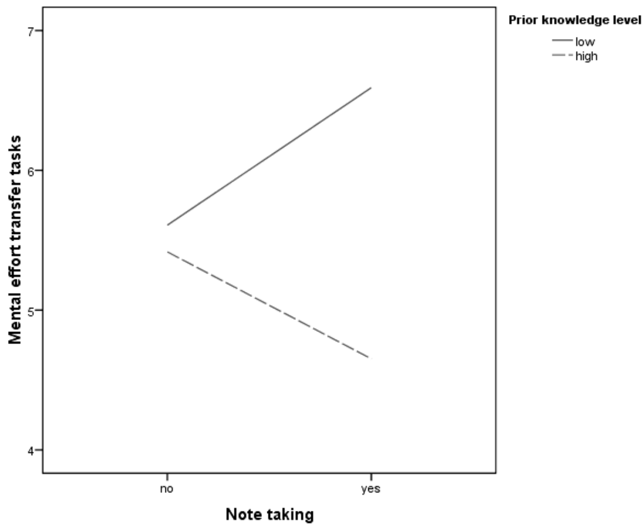


Figure 3.2.
Interaction effect between level of prior knowledge and note taking on mental effort during transfer.

Performance

A main effect of prior knowledge on performance was found for both learning tasks (F(1, 57) = 17.235, MSE = 60.001, p < .001, η^2_p = .232) and transfer tasks (F(1, 56) = 22.789, MSE = 41.164, p < .001, η^2_p = .289). As Table 3.1 shows, the high prior knowledge group performed higher on learning tasks and transfer tasks as compared to the low prior knowledge group. No other significant effects were found on performance. There was no interaction effect between level of prior knowledge and note taking on learning task performance (F(1, 56) = .355, MSE = 1.252, *ns*, η^2_p = .006) or transfer test performance (F(1, 55) = .408, MSE = .746, *ns*, η^2_p = .007). Furthermore, although note takers performed higher than participants who did not take notes (see Table 3.1), this difference did not reach statistical significance.

Mental efficiency

An interaction effect between level of prior knowledge and note taking was found on mental efficiency (F(1, 55) = 4.786, MSE = 3.799, p < .05, η^2_p = .08). For high prior knowledge learners, note taking yielded an increase in mental efficiency, whereas note taking yielded the opposite effect on mental efficiency for low prior knowledge learners (see Figure 3.3).

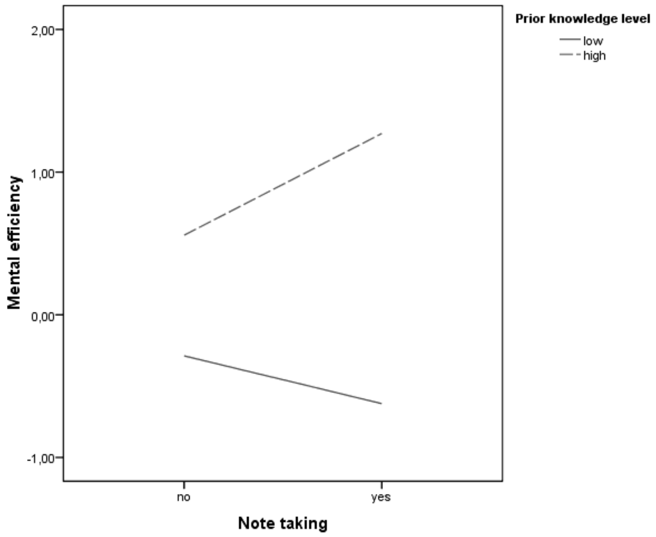


Figure 3.3.
Interaction effect between level of prior knowledge and note taking on mental efficiency.

Post-hoc analyses revealed that mental efficiency of note takers was mediated by their level of prior knowledge. More specifically, mental efficiency of note takers with high prior knowledge was higher than for note takers with low prior knowledge (F(1, 55) = 21.930, MSE = 17.408, p < .001, η^2_p = .285). Figure 3.4 provides an overview of the mental efficiencies for each condition.

In addition to the interaction effect, a main effect of prior knowledge on mental efficiency was found (F(1, 55) = 21.077, MSE = 16.731, p < .001, η^2_p = .277). The high prior knowledge group revealed a higher mental efficiency while working on transfer tasks as compared to the low prior knowledge group (see Table 3.1). No other significant effects were found on mental efficiency.

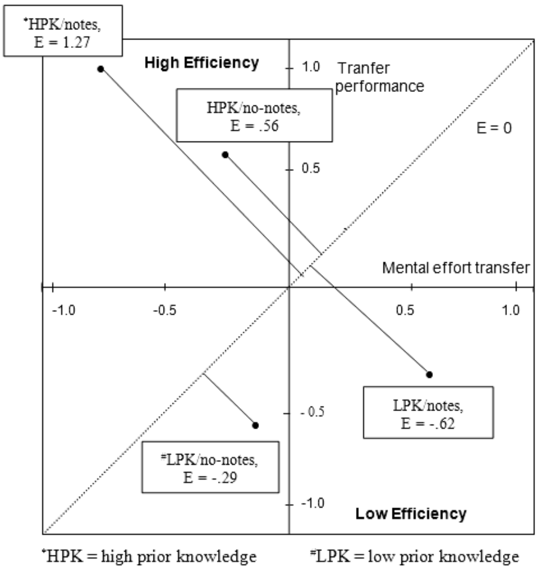


Figure 3.4.
Mental efficiency per condition.

Activated knowledge

Table 3.2 provides the means and standard deviations for the number of concepts, relations between concepts, and correct relations in the notes and the think-aloud protocols.

Table 3.2
Means and standard deviations for number of concepts, relations between concepts, and correct relations in the notes and think-aloud protocols

		Low prior knowledge group (*n* = 20)		High prior knowledge group (*n* = 11)	
		M	*SD*	*M*	*SD*
Notes	Concepts	4.30	4.56	8.18	6.56
	Relations	1.55	4.57	.45	1.04
	Correct relations	1.30	4.01	.27	.65
		Low prior knowledge group (*n* = 12) [#]		High prior knowledge group (*n* = 10) [#]	
		M	*SD*	*M*	*SD*
Protocols	Concepts	7.50	4.85	15.10	7.31
	Relations	2.50	2.58	9.80	5.37
	Correct relations	1.25	1.77	7.50	5.02

[#] Based on a subset of all participants

Notes. A significant difference in number of concepts was found ($t(29) = -1.940$, $p < .05$, $d = .68$). The high prior knowledge group generated significantly more concepts in the notes than the low prior knowledge group. However, both groups did not differ in the number of (correct) relations between activated concepts. The number of relations described in the notes was very low ($M = 1.16$, $SD = 3.73$). Interestingly, the low prior knowledge group showed a tendency to generate more (correct) relations than the high prior knowledge group. However, this seemed to be influenced by two participants in the low prior knowledge group who generated a relatively large number of relations (i.e., 19 and 9 relations of which, respectively, 17 and 7 were correct).

Protocols. Significant differences between both prior knowledge groups were found on the number of concepts ($t(20) = -2.975$, $p < .01$, $d = 1.25$), relations ($t(20) = -4.181$, $p < .001$, $d = 1.73$), and correct relations ($t(10.857) = -3.751$, $p < .01$, $d = 1.66$). The high prior knowledge group generated more concepts in the think-aloud protocols, more relations between activated concepts, and more correct relations than the low prior knowledge group.

Discussion

The main goal of the study presented in this chapter was to investigate the retrieval-directed function of note taking in prior knowledge activation (i.e., mobilisation) for learners with different levels of prior knowledge. Results supported the hypothesis that the effectiveness of the retrieval-directed function of note taking is mediated by the amount of prior domain knowledge learners already possess. For learners with relatively high prior knowledge about the circulatory system, note taking lowered mental effort while working on transfer tasks and increased mental efficiency. For learners with relatively low prior knowledge, note taking yielded the opposite effects on mental effort during transfer and mental efficiency. Post-hoc analyses showed that both mental effort and mental efficiency of note takers were influenced by their level of prior knowledge. More specifically, the invested mental effort of note takers with low prior knowledge was higher than for note takers with high prior knowledge. In addition, the mental efficiency was higher for note takers with high prior knowledge than for note takers with low prior knowledge. Post-hoc analyses also showed that note taking increased the invested mental effort while working on transfer tasks for low prior knowledge learners; the mental effort of low prior knowledge learners who took notes was higher than the mental effort of low prior knowledge learners who did not take notes. This higher mental effort is unlikely to be an artefact of the requirement to take notes because it was found in the transfer phase in which note taking was not allowed. In addition, if this difference in mental effort was an artefact of note taking, this effect should have been even stronger for the learning phase that immediately followed prior knowledge activation during which the notes were taken. Furthermore, the lower mental effort as a result of note taking for high prior knowledge learners also refutes the assumption that high school students always report more effort if they are required to do more.

By externally representing their prior knowledge by means of taking notes, learners with high prior knowledge in a domain are enabled to activate concepts and relate these concepts to one another without having to keep them active in working memory. This retrieval-directed function of note taking reduces the load imposed on working memory and prevents learners from being overloaded by activating prior knowledge. The offloading effect of taking notes facilitates the activation process, which enhances learning for high prior knowledge learners. Although high prior knowledge learners who took notes showed a lower mental effort and a higher mental efficiency than high prior knowledge learners who were not allowed to take notes, this difference did not reach statistical significance. This might be the result of the small sample size; there were only eleven high prior knowledge learners who took notes and thirteen high prior knowledge learners who did not take notes. This explanation is supported by investigating the effect sizes. For mental effort, η^2_p was .037 and for mental efficiency, it was .042. These effect sizes indicate a small to medium effect of note taking lowering mental effort and enhancing mental efficiency for high prior knowledge learners. Replicating the study from this chapter with a larger number of high prior knowledge learners might provide stronger evidence for the hypothesis that retrieval-directed note taking has beneficial effects for learners with sufficient prior domain knowledge.

The results supported the notion that retrieval-directed note taking in prior knowledge activation has no beneficial effects for learners with only limited prior knowledge about the circulatory system. Performance and mental efficiency did not differ depending on whether or not low prior knowledge learners were allowed to take notes while mobilising. Note taking even had a negative effect on experienced mental effort; learners with limited prior knowledge who took notes showed a higher mental effort than low prior knowledge learners who did not take notes. If prior knowledge is very limited, learners might not be able to distinguish relevant from irrelevant concepts or draw relations between activated concepts. This makes it difficult for them to build a coherent external representation of their prior knowledge by taking notes. Therefore, note taking might not have had any offloading effects on working memory for low prior knowledge learners.

When looking closely at the activated prior knowledge, it was shown that high prior knowledge learners generated more concepts, more relations, and more correct relations in the think-aloud protocols than low prior knowledge learners. They also generated more concepts in their notes than low prior knowledge learners. However, both groups did not differ in the number of (correct) relations between activated concepts. There was even a tendency for low prior knowledge learners to generate more (correct) relations in their notes. This was influenced by two low prior knowledge learners who generated many (correct) relations. These learners might have been more skilled in taking notes. Interestingly, one of these learners showed a transfer test performance that was higher than the mean of the high prior knowledge group that took notes (i.e., 7.01 vs. 6.60). This provides support for the assumption that the quality of notes may influence the learning gains. It is not clear why these two learners were able to generate a relatively large number of relations but the possibility that they studied between the prior knowledge test and the actual experiment cannot be excluded. In general, the number of relations in the notes was very low for both high prior knowledge and low prior knowledge learners. This is consistent with Kiewra (1985) who found that relational note taking is difficult for learners.

A practical implication that follows from the study presented here is that retrieval-directed note taking does not necessarily support the activation process and learning. Although learners who took notes while activating their prior knowledge performed somewhat higher than learners who did not take notes, this difference did not reach statistical significance. In addition, learners did not differ in invested mental effort or mental efficiency depending on whether they were allowed to take notes or not. Note taking seemed to be beneficial for learners who already possessed sufficient prior knowledge. For learners who possessed only limited relevant prior knowledge, it was not beneficial to take notes while activating prior knowledge. For them, note taking resulted in an increase in invested mental effort while working on tasks indicating that they might be overloaded by the process of taking notes. Therefore, when instructing students to take notes while activating their prior knowledge, teachers should take their students' levels of prior knowledge into account. In addition, instructing students on how to take notes might be beneficial for learning. The analysis of the notes showed that learners did not generate many relations in their notes. If students are encouraged to establish relationships in their notes, this may strengthen the organising framework facilitating the integration and thus learning of new information.

In the study presented in this chapter, all participants were high school students. Therefore, it is reasonable to conclude that both high and low prior knowledge learners were on the low end of the expertise continuum. Medical students, for example, are considered to have much more elaborated and refined prior knowledge or expertise about the circulatory system than high school students. These learners with relatively high expertise might not benefit from taking notes while activating prior knowledge in the same way as the more knowledgeable high school students in this chapter do. It is possible that the positive effects of note taking fade away or reverse with increasing expertise (the so-called 'expertise reversal effect', see Kalyuga, Ayres, Chandler, & Sweller, 2003). Learners with expertise in a certain domain may already possess a coherent representation of their prior knowledge that can be held in working memory without overloading it. Therefore, note taking might not have any offloading effects for these high expertise learners. Future research should thus extend the continuum of prior knowledge towards higher levels of expertise and investigate the effects of retrieval-directed note taking in prior knowledge activation for learners at different points of this continuum.

Another line of research is related to the influence of the type of representation used to guide prior knowledge activation. In the study presented in this chapter, learners are provided with a static picture that might support them in activating their prior knowledge as compared to not being provided with this picture. But what happens if learners are provided with an animation? Is an animation better able to represent and activate a dynamic domain such as the circulatory system as compared to a static picture? And how is the effectiveness of the representation influenced by learners' prior knowledge? Future research may shed more light on this issue.

Concluding, the study presented here provided evidence that retrieval-directed note taking may exert positive effects on learning. However, these beneficial effects were mediated by the amount of prior knowledge learners already possessed and were restricted to measures of mental effort and mental efficiency. Future research might provide more insights into the beneficial effects of retrieval-directed note taking in prior knowledge activation.

Appendix - Types of completion problems

Mrs. X has diabetes. After every meal, she injects insulin in the vein of her left upper arm. What way does the insulin travel before it reaches the brain?

Type I: Complete solution steps	**Type II**: Rearrange solution steps	Correct solution
1) arm vein	1) superior vena cava	1) arm vein
2) superior vena cava	2) aorta	2) superior vena cava
3) right atrium	3) left atrium	3) right atrium
4) right ventricle	4) right ventricle	4) right ventricle
5) pulmonary artery	5) pulmonary artery	5) pulmonary artery
6) lungs	6) pulmonary vein	6) lungs
7)	7) brain	7) pulmonary vein
8)	8) left ventricle	8) left atrium
9)	9) lungs	9) left ventricle
10)	10) right atrium	10) aorta
11)	11) arm vein	11) brain

Chapter 4

Adapting prior knowledge activation: Combining mobilisation and perspective taking with retrieval-directed note taking

Abstract

This chapter investigates the effects of two prior knowledge activation strategies (i.e., mobilisation and perspective taking) and retrieval-directed note taking during prior knowledge activation. It is hypothesised that the effectiveness of these strategies is mediated by learners' prior knowledge. Mobilisation is expected to be beneficial for learners with lower levels of prior knowledge to help them extend their limited knowledge base. Perspective taking might especially support learners with higher levels of prior knowledge to refine their elaborated knowledge base. Furthermore, retrieval-directed note taking is expected to support the activation process by reducing the load imposed on working memory but only for learners with lower levels of prior knowledge who are easily overwhelmed by prior knowledge activation. The effectiveness of the activation strategy (in terms of learning task performance) and of retrieval-directed note taking (in terms of invested mental effort in the learning phase) was indeed mediated by learners' prior knowledge in the hypothesised directions.

Prior knowledge activation has strong facilitative effects on learning. Schmidt, de Volder, de Grave, Moust, and Patel (1989), for example, activated students' prior knowledge by means of problem-based discussion. Small groups of students were provided with a problem that described the behaviour of a blood cell that was put into pure water or a salt solution (i.e., the problem of osmosis). Students were asked to construct an explanatory model of the blood cell's behaviour in terms of an underlying process using their prior knowledge. A control group discussed a problem related to the apparent ease with which airplanes seem to resist the laws of gravity. After collaboratively discussing the osmosis or airplane problem, students were given a free recall test on osmosis. Students who discussed the problem of osmosis showed higher recall than the control group that did not activate relevant prior knowledge. Prior knowledge activation – in this case by means of problem-based discussion – provided students with a framework that could be used during recall with facilitative effects on learning as evidenced by superior recall.

In this chapter, the effects of two prior knowledge activation strategies, namely, mobilisation and perspective taking, combined with note taking are studied. More specifically, it is investigated how the effectiveness of these activation strategies and note taking during prior knowledge activation is mediated by learners' prior knowledge. The structure of the introduction of this chapter is as follows. First, the facilitative effects of prior knowledge activation on learning are described by outlining the effects of several prior knowledge activation strategies. Here, special attention is paid to mobilisation and perspective taking. Second, traditional note taking research is shortly discussed and the differences with note taking as operationalised in this chapter are emphasised. Third, it is described how note taking during prior knowledge activation may facilitate the activation process and learning. Fourth, it is hypothesised how the effectiveness of mobilisation, perspective taking, and note taking is mediated by learners' prior knowledge.

Prior knowledge activation

If learners activate their prior knowledge, this knowledge is brought from long-term memory to working memory providing learners with what Mayer (1979, p. 134) calls "…an assimilative context of existing knowledge…". However, the *availability* of prior knowledge is not sufficient to reach higher learning outcomes. Learners should *actively use* the available prior knowledge by establishing relationships between the assimilative context held in working memory and new information (Mayer, 1979). So, prior knowledge provides learners with a relevant context in which new information can be integrated.

Many studies using different prior knowledge activation strategies have provided evidence for a strong positive impact of prior knowledge activation on learning. For example, in line with Schmidt et al. (1989), De Grave et al. (2001) used problem-based discussion to activate students' prior knowledge. Students collaboratively discussed a problem of blood pressure regulation or of vision and tried to find explanations for these problems relying on their prior knowledge. Students who discussed the process of blood pressure regulation recalled more information from a text about this topic than the control group that discussed the text-irrelevant topic of vision. By discussing the blood pressure regulation problem, a relevant framework of learners' prior knowledge was built in which new information from the text could be integrated facilitating recall of this information.

Two activation strategies that are important in the context of the study presented in this chapter are mobilisation and perspective taking. These strategies are outlined in the following sections.

Mobilisation

A well-known technique for activating prior knowledge is mobilisation where learners are encouraged to bring to mind all knowledge they have in a certain domain (Peeck, 1982). Machiels-Bongaerts et al. (1993) asked students in two experimental groups to mobilise either names of US states or names of US presidents. A control group mobilised names of composers. Subsequently, all students studied a list containing the names of 32 US states and presidents. Each item on the list was presented for a fixed amount of time. Both experimental groups showed higher recall scores than the control group. This higher recall was entirely caused by enhanced recall of items of the mobilised category; the presidents group recalled more president names than the group that mobilised state names or the control group, whereas the states group outperformed both other groups in recall of state names. These findings indicate that mobilising prior knowledge specifically facilitates the recall of information relevant to the activated knowledge.

In another study, Machiels-Bongaerts et al. (1995) encouraged students to mobilise all knowledge they had about the fishery policy of the European Union and its consequences. A control group activated prior knowledge about a neutral topic (i.e., tennis). Subsequently, all students studied a text describing the effects of the restrictive EU fishery policy on a small imaginary fishermen's village. The text contained information about the background of the fishery policy and its consequences (e.g., a rise in unemployment) that were expected to correspond to the activated prior knowledge of the experimental group. Furthermore, the text contained information that provided additional new information (e.g., an alternative income source) that became important in light of the activated prior knowledge. The experimental group outperformed the control group in recall of information from the text. This higher recall was caused by enhanced recall of information that was explicitly activated and of the new information that became relevant in the context of the activated knowledge. By establishing relations between the activated prior knowledge and the new information, the integration of the new information into the existing knowledge base is facilitated. So, mobilisation enables learners to bridge the gap between their prior knowledge and new information provided to them with beneficial effects on learning.

Perspective taking

Another strategy used to activate learners' prior knowledge is perspective taking. This strategy is often investigated in the context of text processing and comprehension research. Pichert and Anderson (1977), for example, found facilitative effects of assigning a perspective from which a text had to be read. The text described the adventures of two boys in one of the boys' homes while they were skipping school. It contained information that was relevant from the perspective of a potential homebuyer or a burglar. Before reading the passage, participants were instructed to take the perspective of either a homebuyer or a burglar. After reading the text, a free recall test was administered. It was shown that information that was relevant to the assigned perspective was recalled better than perspective-irrelevant information.

These results were replicated by Goetz et al. (1983), who used an expanded version of the skipping school passage. Again, participants read the story from the perspective of either a homebuyer or a burglar. After studying the text, participants rated the importance of sentences and tried to recall everything they could remember from the text. Text elements relevant to participants' assigned perspective were rated more important and were recalled best. For the group that took the burglar perspective, burglar sentences were more important and were recalled better than homebuyer sentences, whereas the opposite pattern was found for the group that read the text from the perspective of a prospective homebuyer. In addition, readers spent more time on sentences containing information that was relevant to their assigned perspective.

Assigning a perspective from which a text should be read results in the activation of an appropriate schema that guides subsequent information processing. As a result of activating a particular schema, a distinction is made between information that is relevant to the previously activated schema and information that is irrelevant in this respect. Selective attention is given to information corresponding with the previously activated knowledge. This results in the selection and in-depth processing of the schema-relevant information, which consequently leads to higher recall of that information. In contrast, information that is not in line with the assigned perspective will be ignored and consequently, not retrieved from memory (Pichert & Anderson, 1977).

Although both mobilisation and perspective taking have beneficial effects on learning, the way these effects are brought about seem to differ. Mobilisation is a *bottom-up* oriented strategy; it serves a broad stage-setting function that provides learners with a relevant context in which new information can be integrated (Peeck et al, 1982). This enables learners to *extend* their prior knowledge. Perspective taking, in contrast, is a *top-down* oriented strategy. Prior knowledge activation by means of taking a specific perspective results in the activation of a corresponding schema, which guides the selection and processing of information relevant to this schema (Pichert & Anderson, 1977). Therefore, perspective taking is a strategy that can support learners to further *refine* their prior knowledge represented in the activated schema.

In addition to the effects of different prior knowledge activation strategies, the study presented in this chapter also investigates the effects of note taking while employing these activation strategies. The next section shortly describes traditional note taking research and emphasises the differences with note taking as operationalised in this chapter.

Traditional note taking versus retrieval-directed note taking

Traditionally, note taking research focused primarily on the effects of taking notes while attending a lecture (e.g., Austin et al., 2002; Kiewra et al., 1991) or reading a text (e.g., Kobayashi, 2009; Slotte & Lonka, 1999). Di Vesta and Gray (1972) distinguished two potential functions of note taking; an encoding function and an external storage function. The *encoding* function of note taking indicates that the process of taking notes *during* learning (e.g., while reading a text) is beneficial for learning. It is investigated by comparing performance scores of learners who took notes with performance scores of learners who did not take notes while being provided with new learning materials. Most studies support the encoding function of note taking; note takers generally achieve higher learning outcomes than no-note takers (for an overview, see Kiewra, 1985; Kobayashi, 2005). It is assumed that taking notes results in a meaningful transformation of the information presented in a lecture or text; it enables learners to organise information and establish personally relevant relations, which make the learning materials more comprehensible. The *external storage* function of note taking assumes that having notes available for review *after* learning enables learners to rehearse ideas presented in a lecture or text, and thus consolidate these ideas. Learners who review their notes generally achieve higher learning outcomes than learners who are not given an opportunity to review, which supports the external storage function of note taking (Kiewra, 1985).

In this chapter, note taking is used to support *prior knowledge activation*. This implies that note taking is used in a different context and for a different purpose as compared to traditional note taking research. First, note taking does not serve an encoding or external storage function. Prior knowledge is already encoded in long-term memory and therefore, note taking has no encoding function. In addition, learners are not given an opportunity to review their notes, so note taking also does not serve an external storage function. In this chapter, note taking primarily serves a *retrieval-directed* function. By means of taking notes, the retrieval of information from long-term memory to working memory during prior knowledge activation is facilitated. Second, the effects of note taking are not investigated *during* (encoding function) or *after* (external storage function) attending a lecture or reading a text but *before* learning. Learners take notes while activating their prior knowledge before the learning materials are provided to them.

The retrieval-directed function of note taking

Retrieval-directed note taking may support prior knowledge activation by reducing the load imposed on working memory. Prior knowledge retrieved from long-term memory is activated in working memory. Therefore, the limited capacity of working memory is an important factor that influences the effectiveness of prior knowledge activation. Learners can hold about seven elements at a time in working memory (Baddeley, 1992; Miller, 1956) but the capacity of working memory is even more severely limited to about three elements when learners are required to simultaneously process elements (Van Merriënboer & Sweller, 2005). This implies that there are limits to the amount of information (i.e., the number of elements) that can be simultaneously activated. Learners might be overloaded by prior knowledge activation, which will hamper the activation process because there is not enough capacity to activate all elements in the existing knowledge base.

Retrieval-directed note taking might be supportive during prior knowledge activation because it enables learners to externally represent their prior knowledge. If learners take notes, they can retrieve and activate many concepts, and relate these concepts to one another without having to keep all concepts active in working memory. This prevents learners from being overloaded by prior knowledge activation with beneficial effects on the activation process and later learning (Sweller, 2003). Used in this way, note taking serves a retrieval-directed function; aided by the notes, learners can retrieve and thus activate more knowledge than they could do without taking notes because working memory is then easily overloaded. If learners are subsequently confronted with new information, they can hold the framework constructed during prior knowledge activation in working memory instead of the separate elements. New information can be integrated into this framework, which bridges the gap between prior knowledge and new information with beneficial effects on learning.

The influence of learners' level of prior knowledge

Mobilisation, perspective taking, and retrieval-directed note taking may all have beneficial effects on prior knowledge activation and learning. However, their effectiveness may be mediated by learners' prior knowledge. Mobilisation is a bottom-up oriented strategy that supports learners to extend their prior knowledge. Especially learners with limited prior knowledge might benefit from a strategy that helps them to elaborate on and extend their limited knowledge base. With increasing prior knowledge, however, learners might benefit most from a strategy that enables them to further refine their already elaborated knowledge base. Therefore, learners with higher levels of prior knowledge might benefit most from a top-down oriented strategy such as perspective taking. In sum, the first hypothesis investigated in this chapter is concerned with the influence of learners' prior knowledge on the effectiveness of mobilisation and perspective taking. More specifically, it is hypothesised that mobilisation is most beneficial for learners at lower levels of prior knowledge. As prior knowledge increases, the beneficial effects of mobilisation are expected to fade away and reverse. At higher levels of prior knowledge, perspective taking is hypothesised to be the most beneficial strategy for activating learners' prior knowledge.

The second hypothesis investigated here is concerned with the effectiveness of retrieval-directed note taking while mobilising or taking a perspective depending on learners' prior knowledge. Retrieval-directed note taking can support prior knowledge activation by reducing the load imposed on working memory. This may be most beneficial for learners who have limited prior knowledge in a certain domain. These learners do not yet possess an organised framework of their prior knowledge, which implies that prior knowledge activation results in the activation of many isolated elements. This may easily overload working memory, which can be prevented by giving learners the opportunity to externally represent these elements by taking notes. However, note taking may loose its supportive effect with increasing prior knowledge. The impact of working memory limitations is mediated by the extent to which the information dealt with has been organised in long-term memory (Sweller, 2005). As expertise develops, increasing amounts of organised information are held in long-term memory that can be brought into working memory as a single entity or element (Ginns et al., 2003; Newell & Simon, 1972). Therefore, the risk that working memory is overloaded by prior knowledge activation decreases with increasing prior knowledge. This implies that note taking may not have any beneficial offloading effects for learners with higher levels of prior knowledge. In sum, learners with lower levels of prior knowledge are expected to benefit from retrieval-directed note taking. With increasing prior knowledge, the beneficial effects of retrieval-directed note taking are expected to fade away and eventually even reverse. At higher levels of prior knowledge, learners benefit most from not taking notes while activating their prior knowledge.

Method

Participants

Sixty-three students (24 males and 39 females; mean age = 18.59 years, *SD* = 3.88) participated in the study presented in this chapter. To guarantee differences in prior knowledge in biology, students from pre-university education (i.e., eleventh graders, *n* = 42) and students from higher education (i.e., nursing and physiotherapy students, *n* = 21) were asked to participate. They were paid €20 for their participation. A multiple regression with the factors *prior knowledge activation strategy* (mobilisation, perspective taking), *retrieval-directed note taking* (yes, no), and *prior knowledge* was used. Prior knowledge was included as a continuous variable to investigate the influence of learners' prior knowledge on the effectiveness of mobilisation, perspective taking, and retrieval-directed note taking. Participants were randomly assigned to one of the four experimental conditions: mobilisation/note taking (*n* = 16), mobilisation/no-note taking (*n* = 16), perspective taking/note taking (*n* = 16), and perspective taking/no-note taking (*n* = 15).

Materials

Prior knowledge test. A prior knowledge test with questions on the circulatory system was administered to assess differences in prior knowledge. This paper-and-pencil test contained 30 multiple-choice questions with four answer options that measured knowledge and understanding of the circulatory system. Questions were related to how blood flows through the body and the heart (e.g., When does blood flow from the atria to the ventricles?), how the heart functions (e.g., How does the electrical system of the heart work?), and related issues (e.g., What is the most common cause for heart failure?). One point was given for each correctly answered question on the prior knowledge test resulting in a maximum score of 30 (*M* =

16.51, *SD* = 5.01). Participants' scores ranged from 8 to 27. Reliability of the prior knowledge test was α = .76 (Cronbach's alpha).

Prior knowledge activation picture. Prior knowledge activation was initiated by means of a picture that illustrated the electrical system and the functioning of the heart. This picture is presented in Figure 4.1.

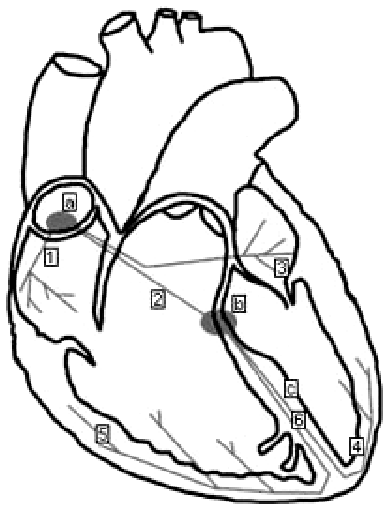


Figure 4.1.
Picture used to activate prior knowledge about the electrical system and the functioning of the heart.

Learning tasks. The learning phase consisted of seven learning tasks, designed according to the principles of the four-component instructional design model (Van Merriënboer & Kirschner, 2007). The first learning task was a worked-out example that contained the main principles necessary to solve the remaining learning tasks. It described how blood flows through the heart and the body, how the electrical system of the heart works, and how this electrical activity is related to the functioning of the heart. After the worked-out example that contained high built-in support, four tasks with diminishing learner support were presented. Learner support was provided by using two completion problems and two reversal problems. In the first completion problem, part of the solution was given and had to be completed by the participants to solve the problem. In the second completion problem, all solution steps were given in a random order and had to be rearranged to solve the problem. In the Appendix, these two types of completion problems are illustrated by applying them to the same problem. The two reversal problems provided the correct solution to the participants, who had then to use backward reasoning to explain why this solution fitted the problem posed. For example, a graph that illustrated the volume of blood in the ventricles of the heart was presented. In addition, three illustrations of the heart that represented a particular phase in the heart cycle (i.e., systolic phase of the atria, systolic phase of the ventricles, and diastolic phase of the heart) were provided. The correct answer concerning which of these three illustrations represented the blood volume in the graph was given and participants had to explain why this particular illustration fitted the graph. Finally, participants had to solve two conventional problems without any support (i.e., no solution steps or correct solutions were provided). For example, participants were asked to describe the different activities that occur during the systolic phase of the ventricles.

Transfer test tasks. The test phase consisted of six transfer tasks. These transfer tasks required participants *to apply* the principles learned during the learning phase, and were used to assess participants' knowledge and understanding of the electrical system and the functioning of the heart. For example, participants had to explain how shrinking of the valves between the left atrium and ventricle as a result of endocarditis can lead to unconsciousness. Reliability of the transfer tasks was α = .59 (Cronbach's alpha).

Scoring

Performance. For each learning task and transfer task, partial credits were given for a correct solution step or answer resulting in a maximum score of 1 for each task.

Mental effort. Mental effort was measured using the mental effort rating scale of Paas (1992). Participants rated their invested mental effort on a 9-point scale ranging from '*very, very little effort*' (1) to '*very, very much effort*' (9). This measure provided an indication of how much mental effort participants had to invest to complete the prior knowledge test, activate their prior knowledge, and solve each learning task and transfer task.

Time-on-task. For each learning task and transfer task, time to solve the problem was automatically recorded.

Activated knowledge. Activated knowledge was measured by analysing the notes taken by the note taking groups and think-aloud protocols recorded in a randomly selected subset (*n* = 15) of all participants. The protocols were registered during prior knowledge activation using a headset and Audacity version 1.2.6 (http://audacity.sourceforge.net), and provided information on the knowledge that was activated by the participants. The notes and think-aloud protocols were scored according to a coding scheme for determining relevancy and correctness of the activated prior knowledge. This coding scheme contained all important concepts necessary for solving learning tasks and transfer tasks. The worked-out example was used to distinguish these important concepts (e.g., Purkinje fibers, ventricles) and relations between these concepts (e.g., electrical activity in the His bundle is conducted to the Purkinje fibers, blood flows from the ventricles to the pulmonary artery and the aorta if the ventricles contract). Two independent raters scored the number of concepts, the number of relations, and the number of correct relations using the coding scheme. Interrater reliability was r = .97 (intraclass correlation).

Procedure

To avoid potential interference with prior knowledge activation, the prior knowledge test was administered at least five days before the experiment. In the experimental session, prior knowledge was activated once before participants started to work on the tasks. Prior knowledge activation was initiated by the prior knowledge activation picture that illustrated the electrical system and the functioning of the heart. This picture was presented on a computer screen for 5 minutes. Instructions given to participants depended on the assigned condition. Participants in the mobilisation conditions were instructed as follows: "*…bring to mind everything you know about the electrical system and the functioning of the heart using the picture presented on the screen. How does the electrical system of the heart work? And what happens in the heart as a result of the electrical activity? Try to establish relations between the different things you already know…"*. Participants in the perspective taking conditions were given the same instructions but were additionally encouraged to "*…take the perspective of a blood cell that travels through the heart and that meanwhile explains how the different parts of the heart work together…"*. Think-aloud protocols were recorded for a subset of all participants.

During prior knowledge activation, all participants were also given a paper version of the prior knowledge activation picture. Only participants in the note taking conditions were instructed to take notes while activating their prior knowledge using this paper version. They were instructed as follows: "*…you have to take notes while activating your prior knowledge. And again, try to establish relations between the different things you already know…"*. Participants in the no-note taking conditions were not allowed to take notes. After activating their prior knowledge, all participants were asked to hand in the paper version of the picture to prevent participants in the note taking conditions from using their notes while working on the tasks.

Subsequently, the learning phase started. First, all participants studied the worked-out example by reading the provided information carefully. Then, participants completed the two completion problems, worked on the two reversal problems, and solved the two conventional tasks. After finishing the learning phase, the transfer phase started in which participants solved the transfer tasks. Participants in the note taking conditions were not allowed to review or otherwise use their notes while working on the learning tasks and transfer tasks. In addition, all participants were instructed not to take notes while solving the tasks.

Participants rated the amount of mental effort they had to invest (a) after completing the prior knowledge test, (b) after activating their prior knowledge by means of mobilisation or perspective taking, (c) after each learning task, and (d) after each transfer task. All tasks and mental effort scales were presented on the computer screen. Participants were allowed to work on the tasks at their own pace.

Results

Multiple regression analyses were used to analyse the effects of mobilisation, perspective taking, and retrieval-directed note taking on performance and mental effort depending on learners' prior knowledge. The dichotomous variables *prior knowledge activation strategy* and *retrieval-directed note taking*, and the continuous variable *prior knowledge* were used in the analyses. In addition, interaction terms were created by multiplying the centred scores on the prior knowledge test with the centred dichotomous values of respectively the prior knowledge activation strategy (mobilisation = -1; perspective taking = 1) and note taking (no = -1; yes = 1). This resulted in interaction terms for (1) prior knowledge and activation strategy, and for (2) prior knowledge and note taking. The variables involved in the interactions were centred to prevent unstable estimations as a result of multicollinearity (Field, 2005). For all statistical tests, a significance level of .05 was maintained. Table 4.1 provides an overview of the means and standard deviations for performance, mental effort, and time-on-task for the learning phase and transfer phase.

Table 4.1
Means and standard deviations for performance, mental effort, and time-on-task

	Mobilisation				Perspective taking			
	No-notes		Notes		No-notes		Notes	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Performance learning phase	2.61	1.33	2.12	1.10	2.86	1.75	2.74	1.12
Performance transfer phase	2.43	1.23	1.49	.94	2.60	1.37	2.16	.94
Mental effort learning phase	5.46	1.27	5.46	1.20	5.52	1.81	5.46	.98
Mental effort transfer phase	5.85	1.17	5.90	1.51	6.08	1.70	5.91	1.50
Time-on-task learning phase (sec.)	141	43	110	33	152	57	140	35
Time-on-task transfer phase (sec.)	119	38	102	34	139	49	128	40

Performance

In order to investigate whether mobilisation and perspective taking had differential effects on performance depending on learners' prior knowledge, the interaction between prior knowledge and prior knowledge activation strategy was examined. An interaction effect between prior knowledge and activation strategy was found on learning task performance (B = .057, $SE\ B$ = .027, β = .213, p < .05). At lower levels of prior knowledge, activation through mobilisation was most beneficial for learning task performance. With increasing prior knowledge, this advantage of mobilisation faded away and reversed. At higher levels of prior knowledge, activation through taking a specific perspective became more beneficial than mobilisation (see Figure 4.2).

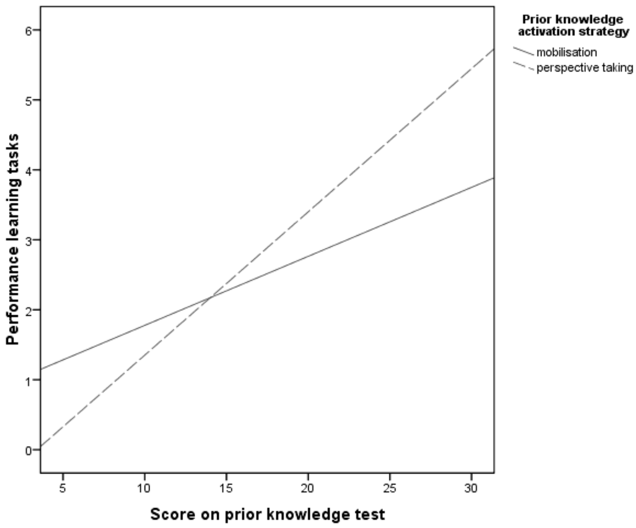


Figure 4.2.
Interaction effect between prior knowledge and prior knowledge activation strategy on learning task performance.

In addition to the interaction effect of prior knowledge and activation strategy, a main effect of prior knowledge was found on learning task performance (B = .161, $SE\ B$ = .027, β = .600, p < .001) and transfer test performance (B = .112, $SE\ B$ = .025, β = .474, p < .001). As prior knowledge increased, performance on learning tasks and transfer tasks also increased. There was also a main effect of note taking on transfer test performance (B = -.356, $SE\ B$ = .124, β = -.303, p < .01). Transfer test performance was higher for learners who were not allowed to take notes during prior knowledge activation as compared to learners who took notes (see Table 4.1). No other main or interaction effects were found on performance.

Mental effort

To investigate the effects of retrieval-directed note taking on mental effort depending on learners' prior knowledge, the interaction between prior knowledge and note taking was investigated. The analysis showed an interaction effect between prior knowledge and note taking on mental effort during the learning phase ($B = .065$, $SE\ B = .028$, $\beta = .250$, $p < .05$). At lower levels of prior knowledge, it was most beneficial if learners took notes while activating their prior knowledge as was shown by a lower amount of invested mental effort while solving learning tasks. With increasing prior knowledge, this beneficial effect of retrieval-directed note taking faded away and reversed. At higher levels of prior knowledge, it was most beneficial if learners did not take notes during prior knowledge activation; no-note taking resulted in lower invested mental effort while working on learning tasks as compared to taking notes (see Figure 4.3).

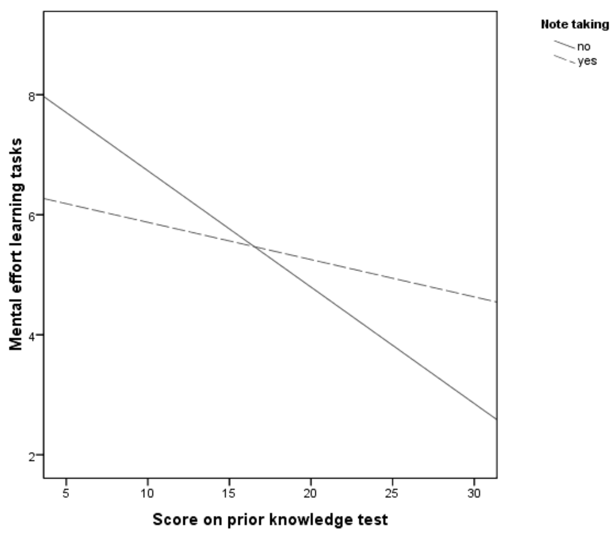


Figure 4.3.
Interaction effect between prior knowledge and note taking on mental effort invested during the learning phase.

In addition to the interaction effect of prior knowledge and note taking, a main effect of prior knowledge was found on invested mental effort during the learning phase ($B = -.130$, $SE\ B = .029$, $\beta = -.496$, $p < .001$) and the transfer phase ($B = -.122$, $SE\ B = .034$, $\beta = -.424$, $p < .01$). As prior knowledge increased, mental effort invested while working on the learning tasks and transfer tasks decreased. No other main or interaction effects were found on invested mental effort.

Time-on-task

In order to exclude possible confounding effects of differences in time spent working on tasks, the effects of time-on-task were also investigated. Main effects of prior knowledge (B = 2.790, $SE\ B$ = .944, β = .335, p < .01) and prior knowledge activation strategy (B = 10.315, $SE\ B$ = 4.648, β = .249, p < .05) were found on time-on-task on the transfer tasks. More specifically, time-on-task spent working on transfer tasks increased with increasing prior knowledge. Furthermore, prior knowledge activation by means of perspective taking resulted in higher time-on-task spent working on transfer tasks than prior knowledge activation through mobilisation (see Table 4.1). The absence of significant interaction effects implies that the interaction effects between prior knowledge and activation strategy on learning task performance, and prior knowledge and retrieval-directed note taking on mental effort invested during the learning phase were not influenced by differences in time-on-task.

Activated knowledge

The notes taken by the note taking groups and the think-aloud protocols registered in a subset of all participants were investigated to gain more insights into the knowledge that was activated by participants. Table 4.2 provides the range, means, and standard deviations for the number of concepts, relations, and correct relations generated in the notes and think-aloud protocols.

Table 4.2
Range, means, and standard deviations for the number of concepts, relations, and correct relations in the notes and think-aloud protocols

		Range	*M*	*SD*
Notes	Concepts	1 - 16	6.30	3.94
	Relations	0 - 12	1.30	2.84
	Correct relations	0 - 6	.96	1.80
Protocols	Concepts	0 - 23	10.27	7.99
	Relations	0 - 23	6.55	8.13
	Correct relations	0 - 23	5.45	7.59

A main effect of prior knowledge was found on the number of concepts (B = .971, $SE\ B$ = .247, β = .795, p < .01), relations (B = 1.050, $SE\ B$ = .221, β = .845, p < .01), and correct relations (B = .944, $SE\ B$ = .225, β = .814, p < .01) generated in the think-aloud protocols. As prior knowledge increased, participants activated more concepts, more relations, and more correct relations in the think-aloud protocols. A main effect of prior knowledge was also found on the number of concepts in the notes (B = .338, $SE\ B$ = .160, β = .420, p < .05). The number of concepts written down in the notes increased with increasing prior knowledge. However, the number of (correct) relations was not influenced by learners' prior knowledge.

Discussion

The main goal of the study presented in this chapter was to investigate the effects of different prior knowledge activation strategies (i.e., mobilisation and perspective taking) combined with retrieval-directed note taking on learning depending on learners' prior knowledge. With regard to the first hypothesis, results showed that the effectiveness in terms of performance of a specific activation strategy was mediated by the amount of prior domain knowledge learners already possessed. As expected, at lower levels of prior knowledge, learning task performance benefitted most if learners' prior knowledge was activated by means of mobilisation. With increasing prior knowledge, the effectiveness of mobilisation diminished and eventually reversed to perspective taking becoming the most effective activation strategy.

The second hypothesis investigated in this chapter assumed that the effectiveness of retrieval-directed note taking is also mediated by learners' prior knowledge and was confirmed in terms of invested mental effort. At lower levels of prior knowledge, it was most beneficial for learners to take notes during prior knowledge activation as was evidenced by a lower invested mental effort during the learning phase as compared to learners who were not allowed to take notes. With increasing prior knowledge, the beneficial effects of retrieval-directed note taking faded away and reversed to a higher effectiveness of not taking notes during prior knowledge activation. At higher levels of prior knowledge, no-note taking resulted in lower invested mental effort while working on the learning tasks than note taking. This is in line with the expertise reversal effect (Kalyuga et al., 2003), stating that instructional support that helps learners with lower levels of prior knowledge becomes ineffective or even detrimental for learners with higher levels of prior knowledge.

The results of this study seem to indicate that aligning the activation strategy and retrieval-directed note taking to learners' prior knowledge supports the learning of new information but not the use and application of this information. Learning benefits if prior knowledge activation is tailored to learners' prior knowledge as was shown by a higher performance or a lower invested mental effort while working on the learning tasks. However, the use and application of the newly learned information did not seem to benefit from aligning prior knowledge activation to learners' prior knowledge, since no beneficial effects were found in the transfer phase. The learning phase might have been too short to foster understanding of the principles learned, which would explain the absence of beneficial effects if learners had to apply the principles while working on the transfer tasks.

In addition to the finding that aligning prior knowledge activation to learners' prior knowledge benefits learning, results also showed that learners learn more effectively and efficiently as prior knowledge increases. More specifically, performance increased and mental effort decreased with increasing prior knowledge. In addition, learners generated more concepts in their notes and think-aloud protocols, and more (correct) relations in the protocols as prior knowledge increased. Interestingly, the number of (correct) relations generated in the notes was not mediated by learners' prior knowledge. The number of (correct) relations was very low for all learners independent of their level of prior knowledge. This is in line with findings from traditional note taking research, which showed that relational note taking is difficult for learners (Kiewra, 1985).

An unexpected finding was the main effect of retrieval-directed note taking in which not taking notes during prior knowledge activation resulted in higher transfer test performance than note taking. This seems to contradict the support found for the encoding and external storage functions in traditional note taking research where taking notes resulted in higher performance. However, there might be a straightforward explanation for this result. Transfer test performance increases with increasing prior knowledge. As prior knowledge increases, learners are not expected to benefit from retrieval-directed note taking and hence, not taking notes might result in the highest transfer test performance. This explanation is supported by exploring the interaction plot of prior knowledge and retrieval-directed note taking for transfer test performance. This plot revealed a trend indicating that as prior knowledge increases, transfer test performance also increases but much stronger for those learners who were not allowed to take notes while activating their prior knowledge. This also provides support for the assumption that the beneficial effects of retrieval-directed note taking depend on learners' prior knowledge.

A practical implication that follows from the study presented in this chapter is that activating learners' prior knowledge is beneficial for learning because it provides learners with a framework in which new information, provided by teachers or learning materials, can be integrated. However, the activation of prior knowledge should be aligned to what learners already know about a certain topic. If learners are still novices in the domain, a bottom-up oriented strategy such as mobilisation should be used to provide learners with a relevant context to elaborate on their limited prior knowledge. With increasing prior knowledge, learners benefit most from a top-down oriented strategy such as perspective taking, which helps them to further refine their already elaborated knowledge base. In addition, retrieval-directed note taking might support prior knowledge activation but it is only recommended for learners with lower levels of prior knowledge who might easily be overwhelmed by the activation process. Furthermore, the effectiveness of retrieval-directed note taking could be strengthened by teaching learners how to externally represent their prior knowledge with an emphasis on relational note taking.

Future research may further explore the effects of mobilisation, perspective taking, and retrieval-directed note taking to provide more insights about the conditions in which these strategies are effective. In this chapter, the beneficial effects were confined to the learning phase. This implies that there is room for adapting and improving the use of these strategies in order to obtain long-term learning gains. Another interesting line of future research is related to the effects of the type of representation used to guide prior knowledge activation. In this study, all participants were provided with a static picture while mobilising or taking a perspective. What happens if learners are provided with an animation? Is an animation better able to represent and activate a dynamic domain such as the circulatory system as compared to a static picture? And how is the effectiveness of the type of representation used to guide prior knowledge activation mediated by learners' prior knowledge? Future research may shed more light on these topics.

In sum, this chapter provided evidence that the effectiveness of mobilisation, perspective taking, and retrieval-directed note taking is mediated by learners' prior knowledge. Aligning the activation strategy and note taking during prior knowledge activation to what learners already know about a certain topic has beneficial effects on learning.

Appendix - Types of completion problems

The heart cycle consists of several phases and activities. Starting with the diastolic phase of the heart, which activities occur during one heart cycle?

Type I: Complete solution steps	**Type II**: Rearrange solution steps	Correct solution
1) blood flowing from atria to ventricles	1) closing of atrioventricular valves	1) blood flowing from atria to ventricles
2) electrical activity in sinus node	2) blood flowing from atria to ventricles	2) electrical activity in sinus node
3) contraction of atria	3) contraction of ventricles	3) contraction of atria
4) electrical activity in atrioventricular node	4) opening of arterial valves	4) electrical activity in atrioventricular node
5)	5) electrical activity in atrioventricular node	5) contraction of ventricles
6)	6) contraction of atria	6) closing of atrioventricular valves
7)	7) electrical activity in sinus node	7) opening of arterial valves

Chapter 5

Prompting prior knowledge activation in biology: The effects of pictures, animations, and verbal representations

Abstract

This chapter investigates the effects of different external representations as prompts for prior knowledge activation in the biology domain. It is hypothesised that the effectiveness of pictures, animations, and verbal representations is mediated by learners' prior knowledge. Pictures are expected to become more beneficial than animations as prior knowledge increases. If learners activate their prior knowledge about the functioning of the heart, they need to mentally animate the pictures. This results in more constructive prior knowledge activation but only for learners with sufficient prior knowledge to engage in such mental animation. For learners with lower levels of prior knowledge, animations are expected to be more beneficial than pictures. Moreover, verbal representations might be more beneficial than both pictures and animations if learners lack the knowledge to comprehend and use the pictorial representations to prompt prior knowledge activation. Results showed that the effectiveness of external representations as prompts for prior knowledge activation is indeed mediated by learners' prior knowledge.

Research has repeatedly and consistently shown that prior knowledge activation has beneficial effects on learning. Chi et al. (1994), for example, activated students' prior knowledge by asking them to self-explain each sentence of a text about the circulatory system. After reading a sentence, students were prompted to think about the information each sentence provided to them. Students in the control group read the same text twice without being prompted to self-explain. To investigate the knowledge gains, students' knowledge and understanding about the circulatory system were assessed before and after reading the text. Students who generated self-explanations using their prior knowledge had higher knowledge gains than students who read the text without self-explaining. The process of prior knowledge activation by means of self-explaining facilitated the integration of provided learning materials with existing knowledge with beneficial effects on learning and understanding the learning materials.

This chapter focuses on the effects of pictorial and verbal external representations as prompts for prior knowledge activation in the biology domain. More specifically, it is investigated how the effectiveness of pictures, animations, and verbal representations is mediated by learners' prior knowledge. The structure of the introduction of this chapter is as follows. First, the beneficial effects of prior knowledge activation on learning are shortly described by illustrating the effects of several prior knowledge activation strategies. Second, research findings on different types of external representations and their dis/advantages are outlined. Third, it is described how pictures, animations, and verbal representations can be used as prompts for prior knowledge activation, and how their effectiveness is mediated by learners' prior knowledge.

Prior knowledge activation

In line with Chi et al. (1994), many studies using different prior knowledge activation strategies such as problem analysis (e.g., De Grave et al., 2001; Schmidt et al., 1989), perspective taking (e.g., Anderson, Pichert, & Shirey, 1983; Goetz et al., 1983), and mobilisation (e.g., Machiel-Bongaerts et al., 1993, 1995) have provided evidence for the beneficial effects of prior knowledge activation on subsequent learning. Problem analysis is similar to self-explanation in that learners activate their prior knowledge when constructing explanations for a presented problem. Learners are, for example, asked to collaboratively discuss and explain the problem of osmosis (i.e., the swelling and shrinking of a red blood cell in pure water and a salt solution). When formulating hypotheses regarding the principles that underlie the process of osmosis, learners rely on their prior knowledge (Schmidt, 1982; Schmidt et al., 1989). Problem analysis facilitates elaboration based on prior knowledge, which enhances the integration of new knowledge into the existing knowledge base. This enhances recall of the new knowledge by making it more accessible (De Grave et al., 2001).

Perspective taking is an activation strategy often used in the context of text comprehension research. Before reading a text, learners are assigned a specific perspective (e.g., the perspective of a burglar or a prospective homebuyer, see Anderson et al., 1983; Goetz et al., 1983). Assigning a perspective from which a text should be read results in the activation of a corresponding schema in memory, which guides subsequent processing. Attention is selectively focused on information that is relevant in light of the activated schema, which enhances recall of this information (Pichert & Anderson, 1977).

Mobilisation is a frequently used activation strategy in which learners are explicitly encouraged to bring to mind everything they know about a specific topic (Peeck, 1982). For example, Machiels-Bongaerts et al. (1995) asked students to mobilise their prior knowledge about the fishery policy of the European Union. These students subsequently recalled more information from a text about the effects of the fishery policy and its consequences for a fictitious fishery village than a control group that activated irrelevant prior knowledge about tennis. Mobilisation serves a broad stage-setting function that encourages learners to build a relevant context based on their prior knowledge (Peeck et al., 1982). New information can be integrated in the activated framework resulting in higher recall and better understanding of the newly encountered information.

It is important to emphasise that the *availability* of prior knowledge is not sufficient to attain higher learning outcomes. Learners need to *activate* and *actively use* the available prior knowledge. If learners activate their prior knowledge, this knowledge is retrieved from long-term memory and activated in working memory. Prior knowledge provides learners with a framework in which new information can be integrated by establishing relations between the existing knowledge held in working memory and new information provided to learners. This results in the elaboration and refinement of the framework with beneficial effects on learning (Mayer, 1979).

External representations

Until now, researchers have mainly used verbal instructions (e.g., '…take the perspective of…', '…bring to mind everything you know about…') to activate learners' prior knowledge. Pictorial representations such as static pictures or animations are rarely used. Before investigating the use and effectiveness of pictorial representations as prompts for prior knowledge activation, the different types of external representations and their relative advantages for learning are outlined.

There are two basic forms of external representations, namely, verbal and pictorial representations. Verbal representations are descriptive and use symbols to represent the subject. Pictorial representations are depictive, consist of icons, and correspond on a one-to-one basis to the subject they represent (e.g., a picture of the heart is similar to its corresponding real-life referent). Because information can be directly inferred, pictorial representations are often seen as more useful for representing knowledge than verbal representations, especially if spatial and temporal relations should be conveyed. In contrast, verbal representations might be more suitable for expressing abstract rather than concrete knowledge (Larkin & Simon, 1987; Schnotz, 2005). For example, a picture of the heart would be very suitable for inferring spatial information such as '*the sinus node is situated in the upper part of the wall of the right atrium*'. However, more abstract knowledge such as '*chronic heart failure is related to lifestyle*' is easily conveyed in a verbal representation but requires many pictorial representations to adequately represent it (e.g., a person smoking, eating fatty food, sitting on the couch watching television, etc.).

Pictorial representations are often used as *adjuncts* to textual learning materials to support understanding and learning. These representations might be especially useful in domains in which it is important that learners understand the organisation and functioning of the domain or system such as the circulatory system (Chi et al., 1994). In this case, pictorial representations might be supportive because they convey spatial relations (e.g., the structure of the circulatory system) and temporal relations (e.g., the functioning of the heart as a result of electrical activity). Pictures and animations are two well-known examples of pictorial representations. The most important difference between these two types of representations is that pictures are static and especially useful for conveying spatial relations, whereas animations are dynamic and especially useful for conveying processes. In other words, what animations add to pictures is change over time (Tversky et al., 2002).

Both pictures and animations have their advantages and disadvantages. For example, animations might help learners to mentally visualise a specific process, which reduces cognitive load as compared to a situation in which learners have to reconstruct this process from static pictures. On the other hand, animations often provide transient information, which might enhance cognitive load because learners must keep previous frames of the animation in working memory and integrate newly provided frames in this mental representation in order to reach full understanding. Because pictures are static and can be reinspected, they do not have this disadvantage (Höffler & Leutner, 2007).

Research findings are inconsistent with regard to whether pictures or animations are superior in supporting learning. In their review study, Tversky et al. (2002) did not find any evidence that animations have clear advantages over pictures. In addition, if animations proved to be superior, this was often because the animations contained more information than the pictures. Höffler and Leutner (2007) did find an overall advantage of animations over pictures. However, this advantage was moderated by the role of the animations (i.e., representational or decorational), the type of animation (i.e., video-based or computer-based) and the type of requested knowledge (i.e., procedural-motor, declarative, or problem-solving knowledge). Animations were more beneficial than pictures but only if the animations were representational, video-based, and aimed at the acquisition of procedural-motor knowledge.

Another factor that might influence the relative effectiveness of pictures and animations is learners' prior knowledge. ChanLin (2001) found that novices in physics benefitted most from pictures when learning physics concepts. Pictures supported these learners because they visualised more clearly how a conceptual model should be built. Novices were confused by the animations because they lacked the knowledge to simultaneously process and relate the animations and the textual information. More experienced learners performed higher when learning physics concepts aided by animations. However, this advantage of animations was not significantly different from learning physics concepts accompanied by pictures. More experienced learners possessed adequate domain-specific knowledge that enabled them to effectively deal with both pictures and animations.

Pictures, animations, and verbal representations in prior knowledge activation

In this chapter, pictorial representations are used as prompts for prior knowledge activation. This implies that they are used for a different purpose and in a different context than in conventional pictures and animations research. Traditionally, pictures and animations are used as adjuncts to textual learning materials to enhance understanding and support learning. In this context, the pictorial representations contain new information (e.g., labeled components) and are presented *during* learning from the instructional materials. However, for prior knowledge activation, it is important that pictures and animations are as *rudimentary* as possible and exclusively focus on the activation of already existing prior knowledge. For example, the pictures and animations should not contain any labels, because the purpose of the representations is to activate learners' prior knowledge and not to provide new knowledge to them. In addition, pictures and animations are not provided as part of the instructional materials during learning but as prompts for prior knowledge activation *before* these materials are presented. In this context, learners are provided with rudimentary pictures or animations in addition to verbal instructions asking them to activate their prior knowledge using these pictorial representations.

Pictorial representations might be very suitable for prompting prior knowledge activation in domains in which knowledge and understanding of the structure and functioning of a system are important for learning (e.g., biology). Then, especially activation of spatial (i.e., structure) and temporal (i.e., functioning) relations benefits subsequent learning. Because pictures and animations represent these relations, they are expected to be more supportive in prior knowledge activation as compared to verbal-only instructions. However, the effectiveness of pictures, animations, and verbal-only instructions as prompts for prior knowledge activation might be mediated by learners' prior knowledge.

The main research question investigated in this chapter is concerned with differences in effectiveness of pictures and animations depending on learners' prior knowledge. Mental animation processes are expected to influence the effectiveness of pictures and animations (Hegarty, Kriz, & Cate, 2003), and learners' ability to mentally animate might in turn be influenced by their level of prior domain knowledge. Hegarty et al. (2003) investigated the effects of static and animated diagrams when learning about a complex dynamic system (i.e., the flushing cistern). Learners were also asked to predict the behaviour of the system from the static diagrams. Prediction enhanced learning from diagrams by activating learners' prior knowledge about the system and mentally animating motion from the static diagrams using available prior knowledge.

Bogacz and Trafton (2005) found that expert meteorologists mainly use static pictures, from which they extracted large amounts of dynamic information, for predicting the weather. These experts seem to mentally animate the static pictures in order to reason dynamically about them. However, it is unlikely that learners with limited prior knowledge are able to engage in such complex mental animation processes. Therefore, it is expected that for learners with lower levels of prior knowledge, animations are more suitable than pictures for prompting prior knowledge activation about a dynamic system (i.e., the functioning of the heart). Domain novices simply lack the knowledge needed to mentally animate the processes involved in the functioning of the heart from static pictures. Therefore, animations are supportive because they compensate for learners' insufficient skills to imagine processes from pictures using their prior knowledge (Höffler & Leutner, 2007). With increasing prior knowledge, pictures are expected to become more beneficial for prompting prior knowledge activation. If learners possess the knowledge to mentally animate processes from pictures, using pictures rather than animations as prompts might result in more active and constructive prior knowledge activation. Learners are enabled to build their own elaborated mental representation of the functioning of the heart by mentally animating the pictures using their prior knowledge. In contrast, animations do not require these high prior knowledge learners to mentally animate. This may result in a relatively passive activation process if they view the animations without actively building their own mental representation of the heart's functioning by inferring processes.

The second research question investigated in this chapter is more exploratory in nature and aims at examining the influence of learners' prior knowledge on the effectiveness of verbal versus pictorial representations as prompts for prior knowledge activation. Learners can only benefit from a specific instruction if it is tailored to their level of prior knowledge (Kalyuga, 2005). In other words, instructions used to prompt prior knowledge activation are only effective if learners actually possess the knowledge triggered by that specific instruction. Learners need adequate prior knowledge about pictorial representations in order to give meaning to them and comprehend them (De Westelink & Valcke, 2005; Larkin & Simon, 1987). At lower levels of prior knowledge, pictorial representations might not be useful at all because learners lack the knowledge concerning spatial and temporal relations to make sense of the representations and to use them as prompts for prior knowledge activation. In this case, providing learners with a verbal rather than pictorial representation (i.e., simply asking them to activate their prior knowledge about a specific topic) might be more suitable for prompting prior knowledge activation. As prior domain knowledge increases, learners are supposed to possess more adequate knowledge about spatial and temporal relations. Then, triggering their prior knowledge by pictorial rather than verbal-only representations may result in more effective prior knowledge activation.

Method

Participants

Ninety-nine students (34 males and 65 females; mean age = 18.08 years, *SD* = 2.44) participated in the study that was conducted to investigate the research questions outlined earlier. Students from pre-university education (i.e., eleventh graders, n = 59) and students from higher education (i.e., nursing, physiotherapy, and ergotherapy students, n = 40) were asked to participate in order to guarantee differences in prior knowledge concerning the circulatory system. They were paid €20 for their participation. A multiple regression with the factors *type of representation* (pictures, animations, verbal-only representation) and *prior knowledge* was used. Prior knowledge was included as a continuous variable in this study to investigate the influence of learners' prior knowledge on the effectiveness of pictures, animations, and verbal representations as prompts for prior knowledge activation. Participants were randomly assigned to the pictures condition (n = 34), the animations condition (n = 33), and the verbal-only representation condition (n = 32).

Materials

Prior knowledge test. A prior knowledge test with questions about the circulatory system was administered to assess differences in prior knowledge. This paper-and-pencil test contained 25 multiple-choice questions with four answer options that measured participants' knowledge of the circulatory system. Questions were related to how blood flows through the body and the heart (e.g., Through which blood vessels does blood flow from the right leg to the heart?), and how the heart functions (e.g., How does the electrical system of the heart work? What is the function of the heart valves?). One point was given for each correctly answered question on the prior knowledge test resulting in a maximum score of 25 (M = 13.40, SD = 5.02). Participants' scores ranged from 3 to 23. Reliability of the prior knowledge test was α = .81 (Cronbach's alpha).

Representations used to prompt prior knowledge activation. Prior knowledge activation was prompted by means of (a) pictures, (b) animations, and (c) verbal-only representations. Figure 5.1 shows the pictures that were used to prompt prior knowledge activation.

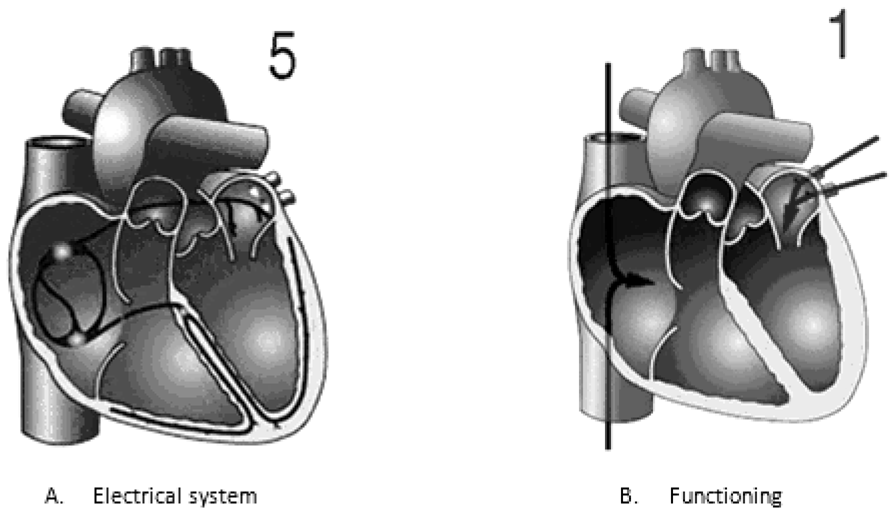


Figure 5.1.
Pictures used to prompt prior knowledge activation about the electrical system (A) and the functioning (B) of the heart.

The pictorial representations illustrated the electrical activity of the heart (see Figure 5.1A) and the corresponding functioning of the heart (see Figure 5.1B). The pictures shown in Figure 5.1 represent static versions of the animations used. For example, the picture illustrated in Figure 5.1A represents the fifth frame of the animation used to prompt prior knowledge activation about the electrical activity of the heart. This animation consisted of five frames and lasted about six seconds, where each frame was presented for approximately one second before the next frame appeared. The animation illustrating the functioning of the heart consisted of three frames and lasted about 4 seconds with each frame being presented for about one second. The pictures and animations were provided for five minutes; participants in the animations condition were not able to stop or otherwise interact with the animations.

Participants in the pictures and animations conditions were instructed to *"…bring to mind everything you know about the electrical system and the functioning of the heart using the pictures [animations] presented on the screen. How does the electrical system of the heart work? And what happens in the heart as a consequence of this electrical activity? Try to establish relations between the different things you already know…"* Participants in the verbal-only representation condition were only provided with this verbal instruction without any references to the pictures or animations.

Learning tasks. Eight learning tasks were presented in the learning phase. The learning tasks were designed in accordance with the four-component instructional design model (Van Merriënboer & Kirschner, 2007). The first learning task was a worked-out example that contained the main principles necessary to solve the remaining learning tasks. It described in detail how blood flows through the heart and the body, how the electrical system of the heart works, and how this electrical activity is related to the functioning of the heart. After the worked-out example with high built-in support, four tasks with diminishing learner support were presented. Learner support was provided by using two completion problems and two reversal problems. A completion problem already provided some solution steps to participants; these steps had to be completed or rearranged in order to solve the problem. A reversal problem already provided participants with the correct solution, encouraging them to use backward reasoning to explain why this solution fitted the problem posed. These two types of problems are illustrated in the Appendix. Finally, three conventional problems were presented that did not contain any learner support (i.e., no solution steps or correct solutions were provided). Participants were, for example, asked to describe what happens if the ventricles contract.

Transfer test tasks. The test phase consisted of six transfer tasks that assessed participants' knowledge and understanding of the electrical system and the functioning of the heart. These transfer tasks required participants *to apply* the principles learned during the learning phase. For example, participants were provided with a diagram illustrating the changes in blood pressure in the left ventricle and the aorta, and changes in blood volume in the left ventricle during a normal heart beat. Based on this diagram, participants had to explain when the heart valve between left ventricle and aorta opened. So, participants had to apply the knowledge that this heart valve opens if the blood pressure in the left ventricle is higher than the blood pressure in the aorta, and that as a consequence the blood volume in the left ventricle diminishes. Reliability of the transfer tasks was α = .52 (Cronbach's alpha).

Scoring

Performance. For each learning task and transfer task, partial credits were given for a correct solution step or answer leading to a maximum score of 1 for each task.

Mental effort. To illustrate the amount of mental effort participants had to invest to complete the prior knowledge test, activate their prior knowledge, and solve each learning task and transfer task, mental effort was measured using the mental effort rating scale of Paas (1992). It was rated on a 9-point scale ranging from '*very, very little effort*' (1) to '*very, very much effort*' (9).

Mental efficiency. To illustrate the efficiency of an instructional procedure (i.e., the type of representation used to prompt prior knowledge activation), mental efficiency (E) was calculated by relating transfer test performance and invested mental effort during the transfer phase using the formula of Paas and van Merriënboer (1993). Performance and mental effort scores were first standardised, and the *z*-scores were entered in the following formula:

$$E = \frac{Z_{Performance} - Z_{Mental\,effort}}{\sqrt{2}}$$

Mental efficiency is high if transfer test performance is higher than might be expected on the basis of the amount of mental effort invested during the transfer phase; it is low if transfer test performance is lower than might be expected on the basis of the amount of mental effort invested during the transfer phase. For example, two instructional procedures may yield the same performance level with different amounts of invested mental effort. In this case, the instructional procedure yielding this performance level with the least amount of invested mental effort is the most efficient one.

Time-on-task. For each learning task and transfer task, time to complete the task was automatically recorded.

Activated knowledge. Activated knowledge was measured by analysing think-aloud protocols recorded in a randomly selected subset (n = 20) of all participants. The protocols were registered while participants activated their prior knowledge using a headset and Audacity version 1.2.6 (http://audacity.sourceforge.net). These protocols provided information on the knowledge that was activated by the participants. For determining relevancy and correctness of activated prior knowledge, think-aloud protocols were scored according to a coding scheme that contained all important concepts necessary for solving learning tasks and transfer tasks. The worked-out example was used to distinguish these important concepts (e.g., sinus node, heart valves) and relations between these concepts (e.g., electrical activity in the sinus node results in contraction of the atria, the atrioventricular valves close if the ventricles contract). Two independent raters scored the number of concepts, the number of relations, and the number of correct relations using the coding scheme. Interrater reliability was r = .98 (intraclass correlation).

Procedure

To avoid potential interference with prior knowledge activation, the prior knowledge test was administered at least one week before the experiment. In the experimental session, prior knowledge was activated once before participants started to work on the tasks. For the pictures and animations conditions, prior knowledge activation was prompted by the pictures or animations that illustrated the electrical system and the functioning of the heart. These pictorial representations were presented on a computer screen for 5 minutes in which participants were instructed to bring to mind everything they knew about the electrical system and the functioning of the heart using the pictures or animations. Participants in the verbal-only representation condition were provided with this verbal instruction without any references to the pictures or animations. Think-aloud protocols were recorded for a subset of all participants.

Subsequently, the learning phase started. First, all participants studied the worked-out example by reading the provided information carefully. Then, participants completed the completion and reversal problems, and solved the remaining three conventional tasks. After finishing the learning phase, the transfer phase started in which participants solved the transfer tasks. Time to solve problems was automatically recorded for each task.

Participants rated the amount of mental effort they had to invest (a) after completing the prior knowledge test, (b) after activating their prior knowledge, (c) after each learning task, and (d) after each transfer task. All tasks and mental effort scales were presented on the computer screen. Participants were allowed to work on the learning tasks and transfer tasks at their own pace.

Results

Multiple regression analyses were used to analyse the effects of type of representation to prompt prior knowledge activation on performance, mental effort, and mental efficiency depending on learners' prior knowledge. Two separate analyses were conducted in order to investigate (1) the effects of pictures versus animations (main research question), and (2) the effects of verbal versus pictorial representations (exploratory research question) taking learners' prior knowledge into account. For investigating the main research question, the variables *prior knowledge* and *type of pictorial representation* were used. An interaction term for prior knowledge and type of pictorial representation was created by multiplying the centred scores on the prior knowledge test with the centred values of type of pictorial representation (pictures = -1; animations = 1). For investigating the exploratory research question, the variables *prior knowledge* and *type of representation* were used. The interaction term for prior knowledge and type of representation was created by multiplying the centred scores on the prior knowledge test with the centred values of type of representation (verbal = -1; pictorial = 1). The variables involved in the interactions were centred to prevent multicollinearity, which may result in unstable estimations (Field, 2005). For the statistical tests, a significance level of .1 was maintained in order to reveal both significant findings and trends. Table 5.1 provides an overview of the means and standard deviations for performance, mental effort, mental efficiency, and time-on-task for the learning phase and the transfer phase.

Table 5.1
Means and standard deviations for performance, mental effort, mental efficiency, and time-on-task

	Pictures (n = 34)		Animations (n = 33)		Verbal-only (n = 32)	
	M	*SD*	*M*	*SD*	*M*	*SD*
Performance learning phase	3.20	1.60	3.51	1.36	3.23	1.59
Performance transfer phase	2.22	1.21	2.34	1.06	1.88	.78
Mental effort learning phase	5.31	1.28	5.25	1.03	5.46	1.36
Mental effort transfer phase	5.70	1.33	5.71	1.35	5.61	1.44
Mental efficiency	.04	1.29	.11	1.15	–.15	1.09
Time-on-task learning phase (sec.)	129	47	132	41	133	46
Time-on-task transfer phase (sec.)	127	54	132	54	120	47

Performance

Pictures versus animations. In order to investigate whether prompting prior knowledge activation by means of pictures or animations had differential effects on performance depending on learners' prior knowledge, the interaction between prior knowledge and type of pictorial representation was examined. An interaction effect between prior knowledge and type of pictorial representation was found on performance on the learning tasks (*B* = -.068, *SE B* = .032, *β* = -.226, *p* < .05). At lower levels of prior knowledge, learning task performance benefitted most from prompting prior knowledge activation by means of animations. As prior knowledge increased, the beneficial effect of providing participants with animations faded away and reversed. As hypothesised, pictures became more effective for prompting prior knowledge activation for learners at higher levels of prior knowledge (see Figure 5.2).

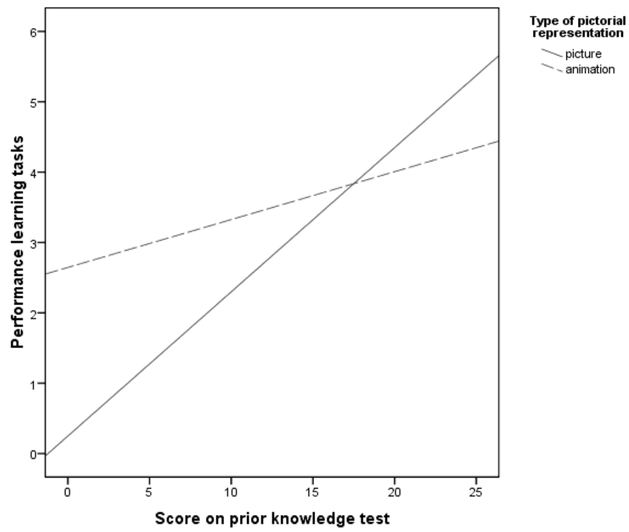


Figure 5.2.
Interaction effect between prior knowledge and type of pictorial representation on learning task performance.

In addition to the interaction effect between prior knowledge and type of pictorial representation, a main effect of prior knowledge was found on learning task performance (*B* = .136, *SE B* = .032, *β* = .458, *p* < .001) and transfer test performance (*B* = .142, *SE B* = .023, *β* = .626, *p* < .001). As prior knowledge increased, performance on the learning tasks and transfer tasks also increased.

Verbal versus pictorial representations. The investigation of the influence of learners' prior knowledge on the effectiveness of verbal and pictorial representations revealed a marginally significant interaction between prior knowledge and type of representation on transfer test performance (*B* = .034, *SE B* = .018, *β* = .164, *p* < .1). There was a trend indicating that transfer test performance benefitted most from prompting prior knowledge activation by a verbal-only representation at lower levels of prior knowledge. With increasing prior knowledge, the beneficial effect of providing learners with a verbal representation diminished and reversed to pictorial representations becoming more effective for prompting prior knowledge activation (see Figure 5.3).

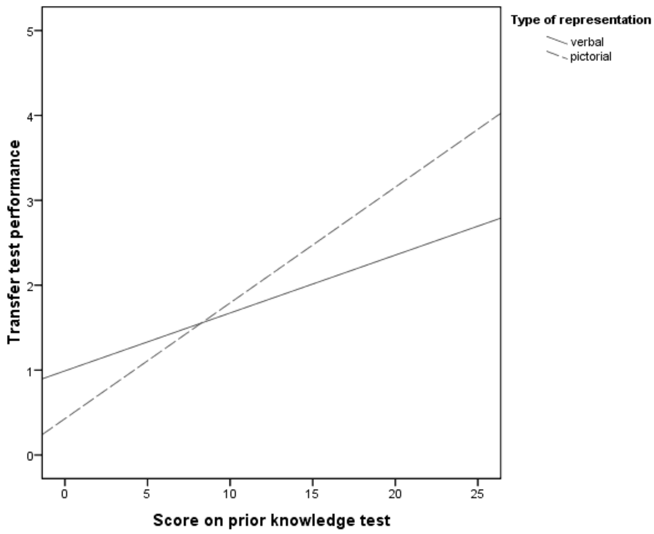


Figure 5.3.
Marginally significant interaction effect between prior knowledge and type of representation on transfer test performance.

In addition to this trend, a main effect of prior knowledge was found on both learning task performance (*B* = .150, *SE B* = .027, *β* = .497, *p* < .001) and transfer test performance (*B* = .113, *SE B* = .017, *β* = .545, *p* < .001). Performance on the learning tasks and transfer tasks increased with increasing prior knowledge. No other main or interaction effects were found on performance.

Mental effort

Pictures versus animations. When testing the influence of learners' prior knowledge on the effectiveness of pictures and animations as prompts for prior knowledge activation, no interaction between prior knowledge and type of pictorial representation was found on mental effort. However, a main effect of prior knowledge was found on mental effort invested during the learning phase (*B* = -.100, *SE B* = .027, *β* = -.430, *p* < .001) and the transfer phase (*B* = -.101, *SE B* = .032, *β* = -.377, *p* < .01). Mental effort invested while working on learning tasks and transfer tasks decreased with increasing prior knowledge.

Verbal versus pictorial representations. The investigation of the effectiveness of verbal and pictorial representations depending on learners' prior knowledge revealed a marginally significant interaction between prior knowledge and type of representation on mental effort invested during the transfer phase (B = -.050, $SE\ B$ = .028, β = -.183, p < .1). There was a trend indicating that at lower levels of prior knowledge it was most beneficial to prompt prior knowledge activation by a verbal-only representation as was shown by a lower amount of invested mental effort to solve the transfer tasks. The effectiveness of the verbal representation seemed to be unaffected by increasing prior knowledge, whereas the effects of pictorial representations became stronger as prior knowledge increased. Prompting prior knowledge activation by means of pictorial representations decreased the amount of invested mental effort with increasing prior knowledge (see Figure 5.4).

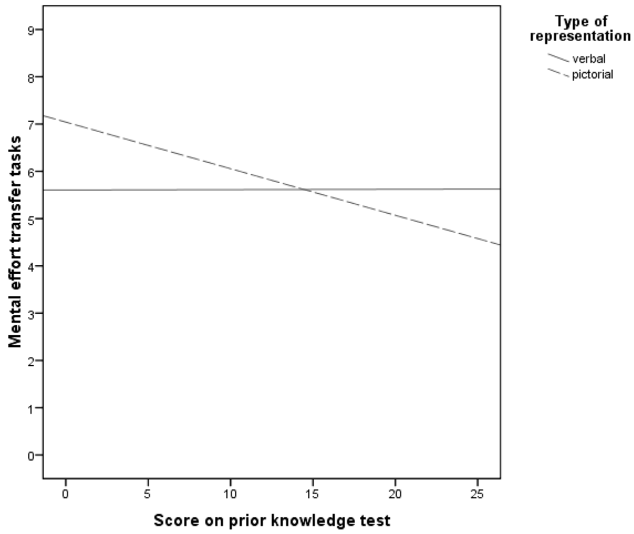


Figure 5.4.
Marginally significant interaction effect between prior knowledge and type of representation on mental effort during the transfer phase.

In addition to this trend, a main effect of prior knowledge was found on mental effort invested in the learning phase (B = -.073, $SE\ B$ = .024, β = -.301, p < .01) and the transfer phase (B = -.065, $SE\ B$ = .027, β = -.240, p < .05). As prior knowledge increased, the amount of mental effort invested while working on the learning tasks and transfer tasks decreased. No other main or interaction effects were found on invested mental effort.

Mental efficiency

Pictures versus animations. When testing the efficiency of pictures and animations depending on learners' prior knowledge, a marginally significant interaction between prior knowledge and type of pictorial representation was found on mental efficiency (*B* = -.044, *SE B* = .025, *β* = -.176, *p* < .1). There was a trend that indicated that it was most efficient to prompt prior knowledge activation by means of animations at lower levels of prior knowledge. As prior knowledge increased, this beneficial effect of using animations as prompts diminished and reversed. At higher levels of prior knowledge, it was most efficient to prompt prior knowledge activation by means of pictures rather than animations (see Figure 5.5).

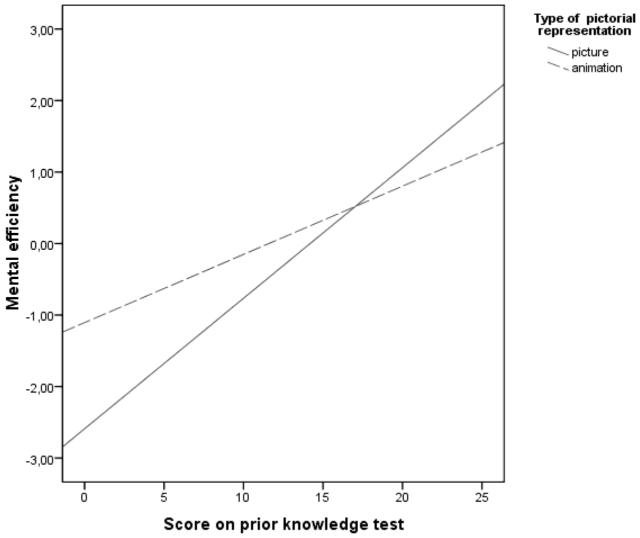


Figure 5.5.
Marginally significant interaction between prior knowledge and type of pictorial representation on mental efficiency

In addition to this trend, a main effect of prior knowledge was found on mental efficiency (*B* = .149, *SE B* = .025, *β* = .610, *p* < .001). With increasing prior knowledge, mental efficiency also increased.

Verbal versus pictorial representations. When exploring the influence of learners' prior knowledge on the efficiency of verbal and pictorial representations, an interaction effect between prior knowledge and type of representation was found on mental efficiency (*B* = .049, *SE B* = .022, *β* = .208, *p* < .05). At lower levels of prior knowledge, it was most beneficial to prompt prior knowledge activation by means of a verbal-only representation. With increasing prior knowledge, the beneficial effect of this verbal representation diminished and reversed to pictorial representations being most efficient for prompting prior knowledge activation (see Figure 5.6).

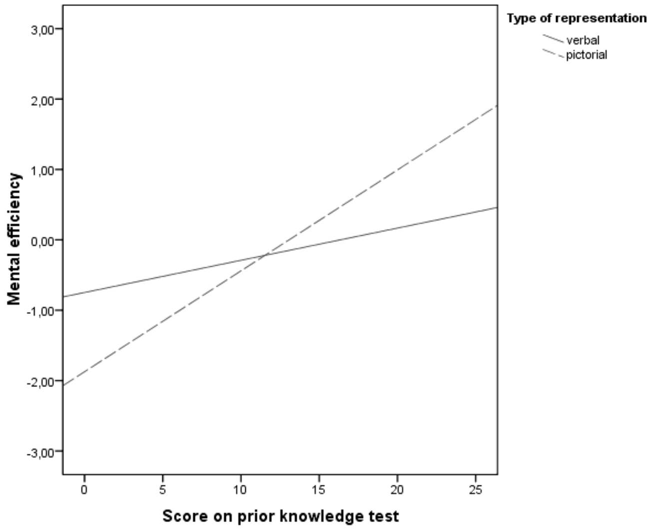


Figure 5.6.
Interaction effect between prior knowledge and type of representation on mental efficiency.

In addition to this interaction effect, a main effect of prior knowledge was found on mental efficiency (*B* = .095, *SE B* = .022, *β* = 404, *p* < .001). Mental efficiency increased as prior knowledge increased. No other main or interaction effects were found on mental efficiency.

Time-on-task

Pictures versus animations. The effects of time-on-task were investigated to exclude possible confounding effects of differences in time spent working on learning tasks and transfer tasks. A main effect of prior knowledge was found on time-on-task in the learning phase (*B* = 3.451, *SE B* = 1.027, *β* = .392, *p* <.01) and in the transfer phase (*B* = 5.238, *SE B* = .1.192, *β* = .488, *p* < .001). Time spent working on the learning tasks and transfer tasks increased with increasing prior knowledge.

Verbal versus pictorial representations. A main effect of prior knowledge was found on time-on-task in the learning phase (*B* = 2.688, *SE B* = .862, *β* = .304, *p* < .01) and in the transfer phase (*B* = 4.060, *SE B* = .957, *β* = .396, *p* < .001). As prior knowledge increased, time spent working on the learning tasks and transfer tasks also increased. No other main or interaction effects were found on time-on-task. The absence of significant interaction effects implies that the interaction effects between prior knowledge and type of (pictorial) representation on performance, mental effort, and mental efficiency were not influenced by differences in time-on-task.

Activated knowledge

In order to gain some insights into the knowledge that was activated, the think-aloud protocols registered in a subset of all participants were investigated. Table 5.2 provides the range, means, and standard deviations for the number of concepts, relations, and correct relations generated in the think-aloud protocols. No main effect of prior knowledge was found on the number of concepts, relations, and correct relations. However, exploring the β-values showed that there was a small to medium effect (i.e., β-values between .2 and .5) indicating that the number of concepts (β = .417), relations (β = .360), and correct relations (β = .420) generated in the think-aloud protocols increased with increasing prior knowledge.

Table 5.2
Range, means, and standard deviations for number of concepts, relations, and correct relations

	Range	*M*	*SD*
Number of concepts	1 - 22	11.59	7.66
Number of relations	0 - 22	7.18	6.91
Number of correct relations	0 - 22	5.82	6.30

Discussion

The main goal of the study presented in this chapter was to investigate how the effects of pictures, animations, and verbal representations as prompts for prior knowledge activation depend on learners' prior knowledge. Results supported the main assumption that the effectiveness of pictures and animations is mediated by the amount of prior domain knowledge learners already possess. For learners with low levels of prior knowledge, it was most beneficial to prompt prior knowledge activation by means of animations as was shown by a higher performance on the learning tasks. As prior knowledge increased, this beneficial effect of animations diminished and reversed. At higher levels of prior knowledge, learning task performance benefitted most if prior knowledge activation was prompted by means of pictures. Although only marginally significant, the trend for mental efficiency was in the same direction as the findings for learning task performance.

The second exploratory research question was concerned with the influence of learners' prior knowledge on the effectiveness of verbal and pictorial representations. Results showed that the effects of verbal and pictorial representations are also mediated by learners' prior knowledge. At lower levels of prior knowledge, it was most beneficial to prompt prior knowledge activation by using only a verbal representation as was evidenced by a higher mental efficiency. However, this beneficial effect of a verbal prompt faded away and reversed as prior knowledge increased. At higher levels of prior knowledge, it was most efficient to use a pictorial prompt to activate learners' prior knowledge. Although the results for transfer test performance and mental effort invested while working on the transfer tasks were only marginally significant, these trends were in the same direction as the findings for mental efficiency.

Notably, the effects of pictures and animations depending on learners' prior knowledge were strongest in the learning phase, whereas learners' prior knowledge influenced the effectiveness of pictorial and verbal representations in the transfer phase only. However, there is no reason to assume that using pictures or animations as prompts depending on learners' prior knowledge especially benefits learning, whereas aligning the use of pictorial and verbal representations to learners' prior knowledge mainly benefits the use and application of learned information (i.e., transfer). Rather, the many marginally significant findings seem to indicate that the sample size in this study might have been too small with negative effects on the statistical power. Therefore, based on the results presented in this chapter, it cannot be excluded that tailoring a specific prompt to learners' prior knowledge might foster both learning and transfer.

In addition to the findings regarding the effectiveness of external representations, it was found that performance increased, invested mental effort decreased, and mental efficiency thus increased with increasing prior knowledge. This implies that learners learn more effectively and efficiently with increasing prior knowledge. Furthermore, there was a trend indicating that learners activated more concepts, more relations, and more correct relations as their prior knowledge increased.

It should be noted that the external representations used to prompt prior knowledge activation are not informationally equivalent. The pictorial representations contain more information than the verbal representations, and the animations convey more information than the pictures because they also illustrate change over time. Therefore, pictorial representations, and especially animations, are susceptible for deducing information from the representations. Learners may learn because of information contained in and deduced from the representations and not from prior knowledge activation per se. However, the results of this study do not support this explanation. Learners with considerable prior knowledge about the circulatory system benefit more from being prompted by pictures even though the animations contain more information than the pictures. Furthermore, learners with limited prior knowledge benefit most if they are not given a pictorial representation at all but are only prompted by means of a verbal instruction. Therefore, it can be confidently concluded that the beneficial effects arise from the process of prior knowledge activation and not from extra information contained in the representations.

A practical implication arising from this chapter is that the use of external representations in prior knowledge activation should be tailored to learners' prior knowledge. Pictures may be most effective for activating learners' prior knowledge about processes because learners need to mentally animate the pictures, and are therefore required to engage in more constructive prior knowledge activation. However, the capability of mental animation heavily depends on learners' prior knowledge. Therefore, using pictures to prompt prior knowledge activation is only suitable for learners who can rely on an elaborated knowledge base to engage in mental animation. For learners with lower levels of prior knowledge, it seems best to encourage them to freely activate their prior knowledge without giving pictorial representations that are yet meaningless to them.

Future research should further investigate the influence of learners' prior knowledge on the effectiveness of different types of representations used to prompt prior knowledge activation. First, the study presented in this chapter could be replicated with a higher number of participants in order to investigate if the sample size indeed influenced the significance of the results. Second, in addition to the representations used in this chapter, learners could be provided with a sequence of static pictures illustrating the different frames of an animation. Providing learners with a sequence of static pictures might be more beneficial for learners with lower levels of prior knowledge because the need to mentally animate diminishes. In contrast, a sequence of pictures might be less effective for learners with higher levels of prior knowledge because it might result in less constructive prior knowledge activation for learners who have the ability to mentally animate the pictures. Third, the effectiveness of the type of representation might not only be influenced by learners' prior knowledge but also by the type of knowledge learners are required to activate. Conceptual knowledge representing key concepts of a domain could possibly be optimally activated by verbal representations, structural knowledge representing the organisation of a domain by means of pictures, and causal knowledge representing the functioning of a domain by means of animations. Future research could provide more insights into these research topics.

Concluding, this chapter provided new insights concerning the use of external representations for prior knowledge activation. Providing learners with pictorial representations as prompts for prior knowledge activation can be a valuable complement to verbal representations but only if learners have adequate prior knowledge to be able to understand and deal with the pictures or animations. Future research may shed more light on the use of external representations for prior knowledge activation.

Appendix - Reversal and completion problems

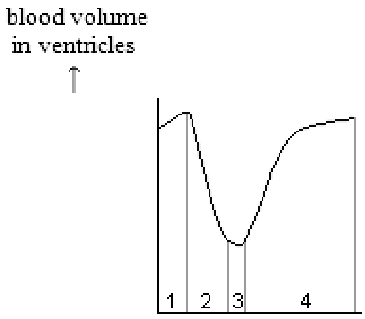
Completion problem

How does the electrical activity of the heart work?

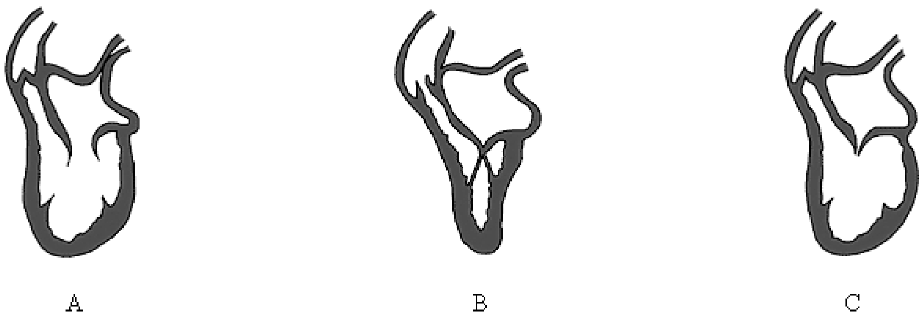
1) electrical activity in the sinus node
2) electrical activity in the left atrium
3) electrical activity in the atrioventricular node
4) ???
5) ???
6) ???

Reversal problem

In the graph presented below, the blood volume in the ventricles is illustrated.



Of the three pictures of the heart presented below, picture A represents trajectory 1 in the graph about the blood volume. Can you explain why?



Chapter 6

General discussion

In this chapter, the main findings from the studies presented in this dissertation are summarised and discussed in terms of conclusions and theoretical implications. In addition, some limitations of the studies and their consequences for interpreting the results are shortly described. Furthermore, practical implications that follow from the studies are discussed and directions for future research are outlined.

Conclusions and theoretical implications

In the past decades, research on prior knowledge activation has consistently shown that activating learners' prior knowledge has beneficial effects on learning. If learners activate their prior knowledge, they can use it as a framework for establishing relations between the knowledge they already possess and new information provided to them. By integrating new information into the existing knowledge base, learning is facilitated (Mayer, 1979). The main aim of the research described in this dissertation was to investigate how prior knowledge activation could be tailored to learners' level of prior knowledge in order to increase the beneficial effects of prior knowledge activation on learning. In Chapter 2, a theoretical framework was presented for prompting prior knowledge activation and reinforcing the activation process. It was outlined that external representations such as pictures, animations, and notes can be used to initiate prior knowledge activation. However, the effectiveness of these external representations for prompting and reinforcing prior knowledge activation was assumed to be mediated by learners' prior domain knowledge.

The studies described in Chapters 3 and 4 focused on investigating the reinforcing effects of taking notes during prior knowledge activation on learning depending on learners' level of prior knowledge. Although both studies showed that the effectiveness of retrieval-directed note taking was mediated by learners' prior knowledge, the results of these studies seemed to be contradictory at first sight. The study presented in Chapter 3 showed that retrieval-directed note taking was beneficial for learners with high prior knowledge, whereas the study presented in Chapter 4 showed that it was beneficial for learners with lower levels of prior knowledge. However, for interpreting the results, it is important to take the range of participants' prior knowledge into account. In the study presented in Chapter 3, all participants were eleventh graders from either higher general secondary education or pre-university secondary education. In the study presented in Chapter 4, both eleventh graders from pre-university secondary education and students from higher education participated. In general, students from higher education had considerably more prior domain knowledge than the secondary school students, and the average prior knowledge level of students from pre-university secondary education was higher than that of students from higher general secondary education. Therefore, it is assumed that the eleventh graders from higher general secondary education represented learners with low levels of prior knowledge, the eleventh graders from pre-university secondary education represented learners with intermediate levels of prior knowledge, and the students from higher education represented learners with high levels of prior knowledge.

From this point of view, the study presented in Chapter 3 showed that retrieval-directed note taking yielded a decrease in invested mental effort and an increase in mental efficiency during the transfer phase for learners with intermediate prior knowledge levels, whereas the opposite pattern was found for learners with low prior knowledge levels. Furthermore, the study presented in Chapter 4 showed that it was most beneficial for learners with intermediate levels of prior knowledge to take notes during prior knowledge activation as was shown by a lower amount of invested mental effort in the learning phase. As prior knowledge increased, this beneficial effect of retrieval-directed note taking faded away and eventually reversed. At higher levels of prior knowledge, it was most beneficial for learners not to take notes while activating their prior knowledge. Taken together, the studies presented in Chapters 3 and 4 showed that retrieval-directed note taking is beneficial for learners at intermediate levels of prior knowledge but not for learners at low or high levels of prior knowledge.

In addition to studying the reinforcing effects of retrieval-directed note taking, the study presented in Chapter 4 also investigated the use of two different strategies for activating learners' prior knowledge, namely, mobilisation and perspective taking. It was found that the effectiveness of mobilisation and perspective taking in terms of performance was also mediated by learners' amount of prior knowledge. At lower levels of prior knowledge, prior knowledge activation through mobilisation was more beneficial for learning than by taking a specific perspective as was shown by a higher learning task performance. With increasing prior knowledge, this beneficial effect of mobilisation diminished and eventually reversed. At higher levels of prior knowledge, it was most beneficial to activate learners' prior knowledge by asking them to take a specific perspective. This finding implies that prior knowledge activation may also benefit from aligning the activation strategy to learners' level of prior knowledge.

The study presented in Chapter 5 focused on the effectiveness of external representations for prompting prior knowledge activation. It was found that the prompting effects of pictures and animations in terms of enhancing performance were mediated by learners' prior knowledge. At lower levels of prior knowledge, learning task performance benefitted most from prompting prior knowledge activation by means of animations. As prior knowledge increased, this beneficial effect of providing participants with animations faded away and eventually reversed. Pictures became more effective than animations to prompt prior knowledge activation for learners with higher levels of prior knowledge. Furthermore, results showed that learners' prior knowledge also influenced the effectiveness of pictorial and verbal representations in terms of mental efficiency. At lower levels of prior knowledge, it was most beneficial to only use a verbal representation to prompt prior knowledge activation. With increasing prior knowledge, the beneficial effect of a verbal-only representation diminished and eventually reversed to pictorial representations being the most efficient prompt for prior knowledge activation. This implies that the prompt used to activate learners' prior knowledge should be aligned to their level of prior knowledge.

Taken together, the results of the studies presented in this dissertation provide support for the theoretical framework presented in Chapter 2. External representations can be suitable to prompt prior knowledge activation and to reinforce the activation process but their effectiveness is strongly influenced by learners' level of prior domain knowledge. The framework could be further refined by including which aspects of learning (i.e., performance, mental effort, or a combination of both in mental efficiency) are supported if prior knowledge activation is tailored to learners' prior knowledge. If the use of retrieval-directed note taking is aligned to learners' prior knowledge, the amount of mental effort that has to be invested for learning is diminished and the mental efficiency of the note taking procedure is optimised. Furthermore, performance benefits especially if the activation strategies and the external representations used to prompt prior knowledge activation are tailored to learners' prior knowledge.

A theoretical implication that arises from the research presented in this dissertation is related to the functions of note taking. Traditionally, note taking has been assigned an encoding function and an external storage function (Di Vesta & Gray, 1972). The process of taking notes *during* learning and of reviewing notes *after* learning has been found to be beneficial for learning (cf., Kiewra, 1985; Kobayashi, 2005). However, the research presented in this dissertation shows that note taking may serve a third function *before* learning, that is, a retrieval-directed function during prior knowledge activation. Taking notes while activating prior knowledge facilitates the retrieval of information from long-term memory to working memory. Furthermore, it was shown that this retrieval-directed function of note taking is not beneficial in and of itself; its effectiveness for reinforcing the activation process and facilitating learning depends on learners' level of prior knowledge. So, note taking may serve three functions depending on whether it is used before learning (retrieval-directed function), during learning (encoding function), or after learning (external storage function). Furthermore, for the retrieval-directed function of note taking, the beneficial effects on learning may depend on learners' prior knowledge.

Another theoretical implication is related to the influence of learners' prior knowledge on the effectiveness of pictorial representations. In conventional pictures and animations research, pictorial representations are often used as adjuncts to textual learning materials in order to render the learning materials more comprehensible and to support learning. In this context, pictures often are more beneficial for learners with relatively low levels of prior knowledge, whereas animations are more suitable for learners with higher levels of prior knowledge (e.g., ChanLin, 2001). In this dissertation, it has been shown that pictorial representations can also be used for another purpose, namely, as prompts for prior knowledge activation. In this context, animations are considered to be more effective prompts at lower levels of prior knowledge, whereas pictures are considered to be more effective at higher levels of prior knowledge. This may imply that a specific type of representation is sometimes more beneficial for low prior knowledge learners and sometimes for high prior knowledge learners depending on its specific purpose (e.g., if it is used as adjunct or as prompt). For example, pictures might be more suitable than animations for learners with low levels of prior knowledge if they are used as adjuncts to textual materials in order to foster understanding and learning. But in contrast, if pictures are used as prompts for prior knowledge activation, they might be more suitable than animations for learners with high levels of prior knowledge because the need for mental animation then results in more active prior knowledge activation. So, pictures and animations cannot only be used as adjuncts for textual learning materials but also as prompts for prior knowledge activation, and though in both cases their effectiveness is mediated by learners' prior knowledge, the underlying mechanisms seem to be different.

Limitations

A limitation of the study presented in Chapter 3 is the relatively low number of high prior knowledge learners. In this study, 24 high prior knowledge learners and 37 low prior knowledge learners participated, which resulted in unequal group sizes when assigning high and low prior knowledge learners to the different note taking conditions. More specifically, there were only 11 high prior knowledge learners who took notes, 13 high prior knowledge learners who were not allowed to take notes, 20 low prior knowledge learners who took notes, and 17 low prior knowledge learners who did not take notes. These unequal group sizes have implications for calculating the mental efficiency measure (see Paas & van Merriënboer, 1993), which implies that the results on mental efficiency in the study presented in Chapter 3 should be considered with caution.

A limitation of the studies presented in Chapters 4 and 5 is related to the selection of participants. Both secondary school students and students from higher education participated in these studies in order to extend the continuum from low to high prior knowledge. This may imply that students not only differed in prior knowledge but also in other respects such as interest or motivation. For example, nursing students who chose their study out of interest in health and disease issues might be more interested in the circulatory system than pre-university secondary education students who attended (obligatory) courses in biology. Because participants were randomly assigned to the different conditions, there is no reason to assume that differences between students other than prior knowledge have influenced the results presented in Chapters 4 and 5. However, the influence of other factors such as interest and motivation could have been more closely controlled for.

Another limitation is related to the 'informational' equivalence of the external representations used to prompt prior knowledge activation in the study presented in Chapter 5. The pictorial representations contained more information than the verbal representation and, in turn, the animations contained more information than the pictures by also conveying information about processes (i.e., change over time). Therefore, it might be argued that the pictorial representations, and especially the animations, are more susceptible for deducing information and learning from this process instead of from the process of prior knowledge activation. However, the findings presented in Chapter 5 do not support this assumption. Learners with higher levels of prior domain knowledge benefitted most from being prompted by pictures even though the animations contained more information. In addition, learners with lower levels of prior knowledge benefitted most if they were not provided with a pictorial representation at all but were simply prompted by a verbal instruction only. Still, it cannot be completely excluded that some participants did learn from viewing the pictures or animations and deducing new information from it.

Finally, the marginally significant results found in the study presented in Chapter 5 seem to be the result of a lack of statistical power. Including more participants in this study might have provided stronger evidence for the hypothesis that the effectiveness of external representations as prompts for prior knowledge activation is mediated by learners' prior knowledge.

Practical implications and directions for future research

Based on the findings of the studies presented in this dissertation, guidelines for activating learners' prior knowledge can be formulated. First, external representations can be used to prompt prior knowledge activation. For learners with a low level of prior knowledge, it is best to use only verbal instructions as prompts because this enables them to freely activate their prior knowledge without being restricted by pictorial representations that are yet meaningless to them. For learners with higher levels of prior knowledge, it is most beneficial to use pictorial representations as prompts for prior knowledge activation. More specifically, pictures are the most effective prompts if learners already have the prior knowledge to mentally animate processes from the static pictures resulting in more active prior knowledge activation as compared to inferring these processes from animations. If learners yet lack the knowledge necessary for mental animation, animations are more effective than pictures.

Second, the activation process and later learning can also be facilitated if the strategy used to activate prior knowledge is aligned to learners' prior knowledge. For learners with a low level of prior knowledge, it is most beneficial to activate their prior knowledge by means of mobilisation because this strategy enables them to elaborate on and extend their limited knowledge base. As prior knowledge increases, learners benefit most from an activation strategy such as perspective taking because it helps them to refine their already elaborated knowledge base.

Third, retrieval-directed note taking can reinforce the activation process by reducing the load imposed on working memory during prior knowledge activation. However, this beneficial offloading effect of note taking only occurs if learners have prior knowledge that can be externally represented but that has not yet evolved into a coherent organised structure (i.e., intermediate level). Retrieval-directed note taking will not be beneficial or might even be detrimental if learners do not yet possess knowledge in a certain domain at all (i.e., low level), or if they already have an organised representation of their prior knowledge that can be brought to working memory as one single element without overloading it (i.e., high level). In sum, external representations are very suitable to prompt prior knowledge activation and to reinforce the activation process provided they are tailored to learners' level of prior knowledge.

Future research should further investigate the beneficial effects of retrieval-directed note taking on learning. The findings of the studies presented in Chapters 3 and 4 seem to indicate that the effectiveness of retrieval-directed note taking follows an inverted U-shaped curve; note taking during prior knowledge activation might be beneficial for learners at intermediate levels of prior knowledge but not for learners with low and high levels of prior knowledge. Future research should aim to more exactly pinpoint the level of prior knowledge at which retrieval-directed note taking is beneficial or detrimental for learning. Therefore, it would be interesting to longitudinally study the effects of retrieval-directed note taking while learners are acquiring expertise in a certain domain. Furthermore, it is important to investigate how the quality of retrieval-directed note taking can be further enhanced. The studies presented in Chapters 3 and 4 showed that the number of relations generated in the notes was very low. The effectiveness of retrieval-directed note taking will probably be increased if learners not only generate concepts in their notes but also deliberately try to relate these concepts to one another. If learners build an organised framework of their prior knowledge, the reinforcing effects of retrieval-directed note taking may be strengthened. This could be investigated by comparing the notes and the learning outcomes of students who were taught how to establish relations in their notes (e.g., by making a concept map of their prior knowledge) with the notes and learning outcomes of students who were simply told to take notes without any guidance.

In the study presented in Chapter 4, mobilisation and perspective taking were used as strategies to activate learners' prior knowledge. Other strategies such as problem-based discussion or self-explanation could also be used to initiate prior knowledge activation. Is collaboratively discussing a problem about, for example, heart failure an effective strategy to activate learners' prior knowledge about the circulatory system? And assuming that the group discussing the problem consists of learners with different levels of prior knowledge, which members of the group (i.e., low, intermediate, or high prior knowledge learners) benefit most from this collaborative process of prior knowledge activation?

With regard to the prompting effects of external representations, the effectiveness of the type of representation may not only be mediated by learners' prior knowledge but also by the type of knowledge learners are required to activate. Perhaps, verbal representations are most suitable to prompt conceptual knowledge and to support learners in activating key concepts in a domain. Pictures might be most beneficial for prompting structural knowledge because they represent how a domain is organised, and animations representing processes and motion might be most suitable for prompting causal knowledge about the functioning of a domain. It would be interesting to study which type of representation is most suitable to prompt prior knowledge activation depending on whether conceptual, structural, or causal knowledge should be activated.

In the studies presented in Chapters 3 to 5, prior knowledge activation in the biology domain was investigated. It seems reasonable to assume that the findings of the presented studies are generalisable to other domains in which knowledge of the structure and the functioning of the domain, and a deep understanding of these structures and functions are important for learning (e.g., physics, chemistry). However, to what extent are these findings generalisable to more conceptually oriented domains? How should prior knowledge activation in these domains be prompted and reinforced?

A last line of research might focus on other factors that distinguish learners with different levels of prior domain knowledge such as interest and motivation. Are learners with more prior knowledge in a domain also more interested in the topic than learners with lower levels of prior knowledge? And are they more motivated to activate and use their prior knowledge when being confronted with tasks? If so, it seems relevant to investigate the extent to which these factors influence the activation process, and how interest and motivation can be enhanced in learners with lower levels of prior knowledge. Such motivation-enhancing strategies could then further increase the beneficial effects of prior knowledge activation on learning.

In sum, the research presented in this dissertation provides more insights into how the beneficial effects of prior knowledge activation on learning can be fostered by taking learners' level of prior knowledge into account. More specifically, external representations such as pictures, animations, and notes can be effectively used to prompt prior knowledge activation and to reinforce the activation process if tailored to learners' level of prior knowledge.

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Summary

In the past decades, research has consistently provided evidence for the beneficial effects of the activation of relevant prior knowledge on subsequent learning. The *availability* of prior knowledge alone is not sufficient to reach higher learning outcomes. Learners need to retrieve the available prior knowledge from long-term memory and actually *activate* it in working memory. Prior knowledge provides learners with a framework in which new information can be integrated by establishing relationships between the existing knowledge held in working memory and new information provided to learners (Mayer, 1979).

Learners' amount of prior domain knowledge is an important factor that might mediate the beneficial effects of prior knowledge activation on learning. Prior knowledge activation takes place in working memory and is therefore subject to working memory's limited capacity. Learners can hold about seven elements at a time in working memory (Baddeley, 1992; Miller, 1956). Moreover, the capacity of working memory is even more severely limited if learners are required to simultaneously process those elements; about three elements at a time can be manipulated, related, or contrasted in working memory (Van Merriënboer & Sweller, 2005). However, the impact of working memory limitations is mediated by the extent to which the information dealt with has been organised in long-term memory (Sweller, 2005), which in turn is influenced by learners' level of prior knowledge. For learners with low levels of prior knowledge, knowledge is not yet meaningfully organised; they do not yet know which concepts are relevant in a particular domain and how these concepts are interrelated. Therefore, these learners are especially susceptible to the limitations of working memory, because activating their prior knowledge results in the activation of many isolated elements. Learners with lower levels of prior knowledge could be easily overwhelmed by the process of prior knowledge activation leading them to experience cognitive overload. As a consequence, the activation process itself will be hampered because there is not enough capacity to activate all elements in the existing knowledge base.

In contrast, as prior knowledge increases, increasing amounts of organised information are held in long-term memory that can be brought to working memory

as a single entity or element without overloading it (Ginns et al., 2003; Newell & Simon, 1972). This implies that the activation process of these learners is less susceptible to working memory's limited capacity. Furthermore, this suggests that strategies that might support prior knowledge activation for learners with lower levels of prior knowledge might become ineffective or perhaps even detrimental with increasing prior knowledge (i.e., an *expertise reversal effect* may arise, see Kalyuga et al., 2003). Therefore, it seems important to align prior knowledge activation to learners' level of prior knowledge. This dissertation explores the effects of several strategies such as retrieval-directed note taking, mobilisation, and perspective taking as well as the use of external representations as prompts for prior knowledge activation depending on learners' prior domain knowledge.

Although external representations such as pictures, animations, and notes are rarely used for prior knowledge activation, they can be used to prompt prior knowledge activation and to reinforce the activation process. More specifically, pictures and animations might be very suitable for prompting prior knowledge activation in the science domain. These pictorial representations represent and activate the spatial relations important for learning about the structure of a system such as the circulatory system (how is it structured or built?), and animations also activate the temporal relations important for learning about its functioning (how does it change over time or function?). Furthermore, the load imposed on working memory can be reduced if learners externally represent their prior knowledge by means of taking notes, which is assumed to facilitate the activation process and consequently, learning. However, the effectiveness of external representations for prompting prior knowledge activation and reinforcing the activation process is also assumed to be mediated by learners' prior domain knowledge. For example, learners need adequate prior knowledge in order to be able to comprehend pictures and animations, and use them as prompts to activate their prior knowledge.

The main aim of the studies presented in this dissertation is to investigate how prior knowledge activation can be tailored to learners' level of prior knowledge in order to increase the beneficial effects of prior knowledge activation on subsequent learning. Chapter 2 presents a theoretical framework for prompting prior knowledge activation and reinforcing the activation process in the science domain. This framework provides more insights in how external representations can be used to support prior knowledge activation. Pictures and animations are assumed to be suitable prompts for activating prior knowledge in the science domain. Furthermore, note taking during prior knowledge activation is assumed to reinforce the activation process. Finally, it is argued that the strength of the prompting and reinforcing effects of external representations during prior knowledge activation is mediated by learners' level of prior domain knowledge.

The study described in Chapter 3 investigates the reinforcing effects of note taking on the activation process and learning for high school students with different levels of prior knowledge of the circulatory system. Here, the concept of retrieval-directed note taking is introduced. Retrieval-directed note taking is directed at facilitating the retrieval of information from long-term memory to working memory during prior knowledge activation. If learners externally represent their prior knowledge by means of retrieval-directed note taking, they do not have to keep all elements active in working memory while activating their prior knowledge. This off-loading (i.e., use of the written notes as an external memory) will reduce the load imposed on working memory with beneficial effects on the activation process and later learning. However, the effectiveness of retrieval-directed note taking was expected to be mediated by learners' level of prior domain knowledge. More specifically, learners with limited prior knowledge might not benefit from note taking during prior knowledge activation because they cannot build a coherent external representation from their limited prior knowledge. Results indeed showed that the effectiveness of retrieval-directed note taking in terms of invested mental effort and mental efficiency (i.e., higher performance combined with lower invested mental effort) was mediated by learners' level of prior knowledge. More specifically, retrieval-directed note taking lowered mental effort and increased mental efficiency during the test phase for high school students in the high prior knowledge group, whereas the opposite effect on mental effort and mental efficiency was found for high school students in the low prior knowledge group.

The study presented in Chapter 4 also investigates the effects of retrieval-directed note taking depending on learners' prior knowledge. However, it extends the range of learners' prior knowledge by including both high school students and students from higher education, who have considerably more prior domain knowledge about the circulatory system. In addition to this, it also investigates the effects of two different prior knowledge activation strategies, namely, mobilisation and perspective taking. First, retrieval-directed note taking was assumed to reinforce the activation process by reducing the load imposed on working memory. However, it was expected that note taking during prior knowledge activation loses its beneficial off-loading effects with increasing prior knowledge because the knowledge held in long-term memory is then well organised and can be easily brought to working memory without overloading it. Results show that the effectiveness of retrieval-directed note taking in terms of invested mental effort was again mediated by learners' prior knowledge. At lower levels of prior knowledge, retrieval-directed note taking was beneficial as was shown by a lower amount of invested mental effort while solving the learning tasks. As prior knowledge increased, the beneficial effect of retrieval-directed note taking faded away and reversed. At higher levels of prior knowledge, it was most beneficial if learners did not take notes while activating their prior knowledge.

At first sight, the note taking results of the studies presented in Chapters 3 and 4 seem to contradict each other. However, the range of learners' amount of prior knowledge in both studies differs considerably, which has to be taken into account when interpreting the results. Taken together, the findings of these studies seem to indicate that retrieval-directed note taking is only beneficial for learners with intermediate levels of prior knowledge whose prior knowledge can be externally represented but has not yet developed into a coherent organised structure that can be brought to working memory without overloading it. In contrast, for learners with both relatively low and high levels of prior knowledge, retrieval-directed note taking is ineffective and perhaps even detrimental for learning.

Second, the effectiveness of mobilisation and perspective taking was also expected to be mediated by learners' prior domain knowledge. More specifically, a bottom-up oriented strategy such as mobilisation was hypothesised to be especially beneficial for learners with low levels of prior knowledge because it enables them to elaborate on and extend their limited knowledge base. However, as prior knowledge increases, a top-down oriented strategy such as perspective taking was hypothesised to become more effective than mobilisation because it enables learners to refine their already elaborated knowledge base. Results indeed showed that the effectiveness of a specific activation strategy in terms of performance was mediated by learners' prior domain knowledge. At lower levels of prior knowledge, activation through mobilisation was most beneficial for learning task performance. As prior knowledge increased, this beneficial effect of mobilisation faded away and eventually reversed. At higher levels of prior knowledge, activation through taking a specific perspective became more beneficial than mobilisation.

The study presented in Chapter 5 focuses on the prompting effects of pictures, animations, and verbal-only representations. The main research question investigated in this study focuses on the effects of pictures and animations as prompts for prior knowledge activation depending on learners' prior knowledge. If learners activate their prior knowledge about the functioning of a domain, using pictures as prompts is assumed to result in more constructive prior knowledge activation because this requires them to mentally animate the pictures in order to activate their prior knowledge about processes. However, learners need adequate prior knowledge to engage in such mental animation processes and learners with lower levels of prior knowledge lack this knowledge. Therefore, animations are expected to be more suitable prompts for low prior knowledge learners. Results showed that the effectiveness of pictures and animations in terms of performance was indeed mediated by learners' prior knowledge. At lower levels of prior knowledge, learning task performance benefitted most from prompting prior knowledge activation by means of animations. As prior knowledge increased, the beneficial effect of using animations as prompts faded away and eventually reversed; pictures became more effective for prompting prior knowledge activation at higher levels of prior knowledge.

The exploratory research question investigated in the study presented in Chapter 5 focuses on the influence of learners' prior knowledge on the effectiveness of pictorial and verbal representations as prompts for prior knowledge activation. More specifically, verbal-only representations were hypothesised to be more effective prompts than both pictures and animations if learners lack the knowledge to comprehend and thus use pictorial representations to prompt prior knowledge activation. As prior knowledge increases, pictorial representations were expected to become increasingly beneficial as prompts for prior knowledge activation. Results showed that learners' prior knowledge influenced the effectiveness of verbal and pictorial representations in terms of mental efficiency. At lower levels of prior knowledge, it was most efficient to prompt prior knowledge activation by a verbal-only representation. With increasing prior knowledge, the beneficial effect of using a verbal-only representation as prompt diminished and reversed to pictorial representations being most efficient for prompting prior knowledge activation.

Finally, Chapter 6 provides an overview of the main findings of the studies described in this dissertation and discusses these findings in terms of conclusions and theoretical implications. The most important conclusion that follows from the presented research is that prior knowledge activation has beneficial effects on learning, especially if it is prompted in a way tailored to learners' level of prior domain knowledge. First, retrieval-directed note taking can reinforce the activation process but only for learners who have prior knowledge that can be externally represented but that has not yet developed into a coherent organised structure. Second, the strategy used to activate learners' prior knowledge should also be aligned to how much learners already know about a specific domain. Bottom-up oriented strategies such as mobilisation are especially suitable for learners with lower levels of prior knowledge, whereas top-down oriented strategies such as perspective taking result in more effective prior knowledge activation for learners with higher levels of prior knowledge. Finally, representations used to prompt prior knowledge activation should also be tailored to learners' prior knowledge, where verbal-only representations are most suitable at lower levels of prior knowledge, and animations and pictures are most suitable at higher levels of prior knowledge. Furthermore, Chapter 6 discusses some limitations of the studies and outlines several practical implications that follow from the research presented in this dissertation. The chapter closes with some considerations for future research that might provide more insights into individualised strategies for prior knowledge activation.

Samenvatting

In de afgelopen decennia heeft onderzoek herhaaldelijk aangetoond dat het activeren van voorkennis voordelige effecten heeft op leren. Hierbij is de *beschikbaarheid* van voorkennis niet voldoende om betere leerresultaten te bereiken. Lerenden dienen de beschikbare voorkennis uit het langetermijngeheugen op te halen en in het werkgeheugen te *activeren*. Voorkennis dient als het ware als een kader waarin nieuwe informatie kan worden geïntegreerd door relaties te leggen tussen de bestaande kennis en nieuwe informatie die de lerenden wordt aangereikt (Mayer, 1979).

Het voorkennisniveau van lerenden is een belangrijke, mediërende factor die de voordelige effecten van het activeren van voorkennis op leren zou kunnen beïnvloeden. Het activeren van voorkennis vindt plaats in het werkgeheugen en is daarom onderhevig aan de beperkte capaciteit van dit werkgeheugen. Lerenden kunnen ongeveer zeven elementen tegelijkertijd in het werkgeheugen houden (Baddeley, 1992; Miller, 1956). Daarnaast wordt de capaciteit van het werkgeheugen nog verder beperkt als lerenden tegelijkertijd meerdere elementen moeten verwerken; er kunnen ongeveer drie elementen tegelijkertijd in het werkgeheugen worden gemanipuleerd, aan elkaar gerelateerd of gecontrasteerd (Van Merriënboer & Sweller, 2005). De impact van de beperkingen van het werkgeheugen wordt echter gemedieerd door de mate waarin informatie in het langetermijngeheugen is georganiseerd (Sweller, 2005), wat vervolgens weer wordt beïnvloed door het voorkennisniveau van lerenden. Lerenden met lagere voorkennisniveaus beschikken over kennis die nog niet betekenisvol is georganiseerd; zij weten nog niet welke concepten relevant zijn in een bepaald domein en hoe deze concepten onderling aan elkaar gerelateerd zijn. Dat maakt deze groep lerenden extra gevoelig voor de beperkingen van het werkgeheugen, omdat het activeren van hun voorkennis leidt tot de activatie van veel geïsoleerde elementen. Het werkgeheugen van lerenden met lagere voorkennisniveaus kan daardoor overbelast raken door het activatieproces. Als gevolg hiervan zal het activatieproces zelf gehinderd worden, omdat er onvoldoende capaciteit beschikbaar is om alle elementen in de aanwezige kennisstructuur te activeren. Naarmate de hoeveelheid voorkennis toeneemt, kan er echter een toenemende hoeveelheid georganiseerde informatie vanuit het langetermijngeheugen als één entiteit of element naar het werkgeheugen gebracht worden zonder dat er sprake is van overbelasting (Ginns et al., 2003; Newell & Simon, 1972). Dat betekent dat het activatieproces van lerenden met meer voorkennis veel minder gevoelig is voor de beperkte capaciteit van het werkgeheugen. Daarnaast suggereert dit dat strategieën die het activeren van voorkennis ondersteunen bij lerenden met lagere voorkennisniveaus ineffectief of zelfs nadelig zouden kunnen worden naarmate de hoeveelheid voorkennis toeneemt (d.w.z. er zou een zogenaamd 'expertise reversal effect' kunnen optreden, zie Kalyuga et al., 2003). Daarom lijkt het van belang om het proces van het activeren van voorkennis af te stemmen op het voorkennisniveau van de lerenden. Dit proefschrift onderzoekt de effecten van verschillende strategieën, waaronder 'retrieval-directed note taking', mobilisatie en het aannemen van een perspectief, en het gebruik van externe representaties als 'prompts' voor het activeren van voorkennis afhankelijk van het voorkennisniveau van de lerenden.

Hoewel externe representaties, zoals plaatjes, animaties en aantekeningen, zelden worden gebruikt voor het activeren van voorkennis lijken ze geschikt om voorkennisactivatie te initiëren (d.w.z. 'prompten') en om het activatieproces te versterken. Plaatjes en animaties zouden met name gebruikt kunnen worden om het activeren van voorkennis in het wetenschapsdomein (bv. biologie, natuurkunde, scheikunde) te initiëren. Deze pictoriële representaties representeren en activeren de spatiële en temporele relaties die van belang zijn als het gaat om leren over de structuur en het functioneren van een systeem, zoals de bloedsomloop. Daarnaast kan de belasting die op het werkgeheugen wordt gelegd, worden verminderd als lerenden hun voorkennis extern representeren door middel van het maken van aantekeningen. Dit bevordert naar verwachting het activatieproces en daarmee ook het leren van nieuwe informatie. Echter, er wordt verondersteld dat de effectiviteit van externe representaties om het activeren van voorkennis te initiëren en het activatieproces te versterken ook wordt gemedieerd door de hoeveelheid voorkennis. Zo hebben lerenden bijvoorbeeld voorkennis nodig om de plaatjes en animaties te begrijpen, voordat ze deze als prompts kunnen gebruiken voor het activeren van hun voorkennis.

Het belangrijkste doel van de studies beschreven in dit proefschrift is te onderzoeken hoe het activeren van voorkennis afgestemd kan worden op het voorkennisniveau van de lerenden ten einde de voordelige effecten op leren te bevorderen. Hoofdstuk 2 presenteert een theoretisch kader voor het initiëren van voorkennisactivatie en het versterken van het activatieproces in het wetenschapsdomein. Dit kader verschaft meer inzicht in hoe externe representaties gebruikt kunnen worden om het activeren van voorkennis te ondersteunen. Er wordt verondersteld dat plaatjes en animaties geschikte prompts zijn voor het activeren van voorkennis in het wetenschapsdomein. Daarnaast wordt verondersteld dat het maken van aantekeningen tijdens het activeren van voorkennis het activatieproces kan versterken. Ten slotte wordt beargumenteerd dat de kracht van de initiërende en versterkende effecten van externe representaties tijdens het activeren van voorkennis wordt gemedieerd door het voorkennisniveau.

De studie die in hoofdstuk 3 wordt beschreven, onderzoekt de versterkende effecten van het maken van aantekeningen op het activatieproces en leren voor middelbare scholieren die verschillen in hun voorkennis over de bloedsomloop. Hier wordt het concept 'retrieval-directed note taking' geïntroduceerd. Retrieval-directed note taking is gericht op het faciliteren van het ophalen van informatie uit het langetermijngeheugen naar het werkgeheugen tijdens het activeren van voorkennis. Wanneer lerenden hun voorkennis extern representeren door middel van retrieval-directed note taking hoeven zij tijdens het activeren van voorkennis niet alle elementen actief in het werkgeheugen te houden. De aantekeningen op papier fungeren als het ware als een extern werkgeheugen. Dit zal de belasting die op het werkgeheugen wordt gelegd reduceren met voordelige effecten op het activatieproces en leren. Er werd hierbij echter verwacht dat de effectiviteit van retrieval-directed note taking wordt gemedieerd door het voorkennisniveau. Met name lerenden met een beperkte hoeveelheid voorkennis zouden geen voordeel kunnen halen uit het maken van aantekeningen tijdens het activeren van voorkennis, omdat het hen nog ontbreekt aan de benodigde kennis om een coherente externe representatie van hun voorkennis te creëren. De resultaten lieten inderdaad zien dat de effectiviteit van retrieval-directed note taking, in termen van geïnvesteerde mentale inspanning en mentale efficiëntie (d.w.z. hogere prestatie in combinatie met lagere mentale inspanning), werd gemedieerd door het voorkennisniveau. Retrieval-directed note taking verlaagde de mentale inspanning en verhoogde de mentale efficiëntie tijdens de testfase voor middelbare scholieren met veel voorkennis, terwijl het tegenovergestelde effect werd gevonden voor middelbare scholieren met weinig voorkennis. Voor deze laatste groep verhoogde retrieval-directed note taking de geïnvesteerde mentale inspanning tijdens de testfase, terwijl de mentale efficiëntie werd verlaagd.

De studie die in hoofdstuk 4 wordt gepresenteerd onderzoekt eveneens de effecten van retrieval-directed note taking afhankelijk van de hoeveelheid voorkennis. Deze studie breidt de reikwijdte van de hoeveelheid voorkennis die lerenden bezitten echter verder uit door niet alleen middelbare scholieren bij het onderzoek te betrekken, maar ook studenten die aanzienlijk meer voorkennis bezitten over de bloedsomloop. Daarnaast worden ook de effecten van twee verschillende strategieën om voorkennis te activeren onderzocht, namelijk mobilisatie en het aannemen van een bepaald perspectief. In de eerste plaats werd verondersteld dat retrieval-directed note taking het activatieproces versterkt door de belasting die op het werkgeheugen wordt gelegd te verminderen. Er werd hierbij echter verwacht dat het maken van aantekeningen tijdens het activeren van voorkennis zijn voordelige effecten verliest naarmate de hoeveelheid voorkennis toeneemt. Met toenemende voorkennis wordt de kennis die in het langetermijngeheugen gehouden wordt steeds beter georganiseerd. Dit betekent dat deze kennis als één element naar het werkgeheugen gebracht kan worden zonder hier overbelasting te veroorzaken. De resultaten toonden aan dat de effectiviteit van retrieval-directed note taking, in termen van geïnvesteerde mentale inspanning, opnieuw werd gemedieerd door de hoeveelheid voorkennis. In geval van lagere voorkennisniveaus was retrieval-directed note taking voordelig, zoals werd aangetoond door een lagere hoeveelheid geïnvesteerde mentale inspanning tijdens het oplossen van de leertaken. Naarmate de hoeveelheid voorkennis toenam, begon het voordelige effect van retrieval-directed note taking echter te vervagen en draaide uiteindelijk zelfs om. In geval van hogere voorkennisniveaus was het het meest voordelig wanneer lerenden *geen* aantekeningen hoefden te maken tijdens het activeren van voorkennis.

Op het eerste gezicht lijken de resultaten met betrekking tot retrieval-directed note taking uit hoofdstuk 3 en 4 elkaar tegen te spreken. Het bereik van de hoeveelheid voorkennis verschilde echter aanzienlijk in beide studies wat van belang is voor het interpreteren van de resultaten. Gecombineerd lijken de bevindingen van beide studies erop te duiden dat retrieval-directed note taking voordelig is voor lerenden met een gemiddeld voorkennisniveau. Deze lerenden bezitten reeds een bepaalde hoeveelheid voorkennis die extern gerepresenteerd kan worden, maar die nog niet is vastgelegd in een coherente structuur die naar het werkgeheugen gebracht kan worden zonder overbelasting te veroorzaken. Voor lerenden met een relatief laag of hoog voorkennisniveau daarentegen is retrieval-directed note taking ineffectief en soms zelfs nadelig voor leren.

In de tweede plaats werd in deze studie verwacht dat de effectiviteit van mobilisatie en het aannemen van een perspectief ook werd gemedieerd door de hoeveelheid voorkennis van lerenden. Er werd verondersteld dat een zogenaamde 'bottom-up' georiënteerde strategie als mobilisatie vooral voordelig was voor lerenden met lagere voorkennisniveaus, omdat een dergelijke strategie hen in staat stelt om hun beperkte kennisbasis verder uit te breiden. Naarmate de hoeveelheid voorkennis toeneemt, wordt een zogenaamde 'top-down' strategie, zoals het aannemen van een perspectief, naar verwachting echter effectiever dan mobilisatie. Een top-down georiënteerde strategie stelt lerenden met hogere voorkennisniveaus namelijk in staat om hun reeds uitgebreide kennisbasis verder te verfijnen. De resultaten toonden inderdaad aan dat de effectiviteit van een specifieke activatiestrategie, in termen van een hogere prestatie, werd gemedieerd door de hoeveelheid voorkennis van lerenden. In geval van lagere voorkennisniveaus was activatie door middel van mobilisatie het meest voordelig voor de prestatie op leertaken. Dit voordelige effect van mobilisatie verminderde echter naarmate de voorkennis toenam en draaide uiteindelijk zelfs om. In geval van hogere voorkennisniveaus werd activatie door middel van het aannemen van een specifiek perspectief effectiever dan mobilisatie.

De studie die wordt beschreven in hoofdstuk 5 onderzoekt de initiërende effecten van plaatsjes, animaties en verbale representaties. De belangrijkste onderzoeksvraag die in deze studie wordt bestudeerd, richt zich specifiek op de effecten van plaatjes en animaties als prompts voor het activeren van voorkennis rekeninghoudend met de hoeveelheid voorkennis. Wanneer lerenden hun voorkennis over het functioneren van een domein activeren, wordt verondersteld dat plaatjes leiden tot een constructiever activatieproces, omdat zij de plaatjes mentaal moeten animeren om hun voorkennis over processen te activeren. Lerenden hebben echter voldoende voorkennis nodig om dergelijke mentale animatieprocessen te kunnen uitvoeren en lerenden met lagere voorkennisniveaus ontbreekt het aan deze benodigde voorkennis. Daarom wordt verwacht dat animaties voor deze lerenden geschiktere prompts zijn dan plaatjes. De resultaten toonden aan dat de effectiviteit van plaatjes en animaties, in termen van prestatie, inderdaad werd gemedieerd door de hoeveelheid voorkennis. In geval van lagere voorkennisniveaus profiteerde de prestatie op de leertaken het meest wanneer het activeren van voorkennis werd geprompt door middel van animaties. Dit voordelige effect van het aanbieden van animaties als prompts verminderde echter met toenemende voorkennis en draaide uiteindelijk zelfs om; plaatjes werden effectievere prompts dan animaties voor het activeren van voorkennis bij hogere voorkennisniveaus.

De explorative onderzoeksvraag die in hoofdstuk 5 werd onderzocht, is gericht op het bestuderen van de invloed van de hoeveelheid voorkennis van lerenden op de effectiviteit van pictoriële en verbale representaties als prompts voor het activeren van voorkennis. Wanneer het lerenden ontbreekt aan de benodigde voorkennis om pictoriële representaties te begrijpen en dus te kunnen gebruiken als prompts wordt verondersteld dat het aanbieden van alleen een verbale representatie een effectievere prompt is vergeleken met zowel plaatjes als animaties. Naarmate de hoeveelheid voorkennis toeneemt, wordt echter verwacht dat pictoriële representaties steeds effectievere prompts worden om voorkennis te activeren. De resultaten toonden aan dat de hoeveelheid voorkennis van lerenden de effectiviteit van verbale en pictoriële representaties beïnvloedt in termen van mentale efficiëntie. In geval van lagere voorkennisniveaus was het het meest efficiënt om het activeren van voorkennis alleen door middel van een verbale representatie te initiëren. Naarmate de hoeveelheid voorkennis toenam, nam het voordelige effect van het aanbieden van een verbale representatie echter af en werden pictoriële representaties steeds efficiënter.

Hoofdstuk 6 geeft een overzicht van de belangrijkste bevindingen van de studies die in dit proefschrift zijn beschreven en bespreekt deze bevindingen in termen van conclusies en theoretische implicaties. De belangrijkste conclusie die uit het beschreven onderzoek naar voren komt, is dat het activeren van voorkennis voordelige effecten op leren heeft wanneer dit is afgestemd op het voorkennisniveau van de lerenden. In de eerste plaats versterkt retrieval-directed note taking het activatieproces, maar alleen voor lerenden die reeds de benodigde kennis bezitten die enerzijds extern gerepresenteerd kan worden maar zich anderzijds nog niet heeft ontwikkeld tot een coherente kennisstructuur. In de tweede plaats dient de strategie die wordt gebruikt om voorkennis te activeren ook te worden aangepast aan de hoeveelheid domeinkennis waarover lerenden reeds beschikken. Bottom-up georiënteerde strategieën (bv. mobilisatie) zijn vooral geschikt voor lagere voorkennisniveaus, terwijl top-down georiënteerde strategieën (bv. het aannemen van een bepaald perspectief) resulteren in een effectiever activatieproces in geval van hogere voorkennisniveaus. Ten slotte dienen ook de representaties die worden gebruikt om voorkennisactivatie te initiëren aangepast te worden aan de hoeveelheid voorkennis. Hierbij zijn verbale representaties vooral geschikt bij lagere voorkennisniveaus, terwijl plaatjes het meest geschikt zijn voor hogere voorkennisniveaus.

Hoofdstuk 6 bespreekt daarnaast ook nog enkele beperkingen van de beschreven studies en gaat in op praktische implicaties die naar voren komen op basis van het onderzoek dat in dit proefschrift wordt gepresenteerd. Ten slotte worden er nog een aantal suggesties voor verder onderzoek gedaan dat meer inzicht zou kunnen verschaffen in hoe het activeren van voorkennis verder geïndividualiseerd kan worden.

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