Use of external representations in science

Chapter 12

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

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Introduction

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 a specific problem, students relied on their prior knowledge to account for it in terms of an underlying process. 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 functioned as a bridge between prior knowledge and knowledge still to be acquired. More specifically, problem-based discussion facilitated the integration of new information into the existing knowledge base resulting in higher recall.

This chapter will focus on the use of external representations of low sophistication (i.e., simple pictures and animations, or brief notes with few interrelations) 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 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 hypothesised to be mediated by learners' level of prior knowledge (see Figure 12.1).

[INSERT FIGURE 12.1 ABOUT HERE]

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. 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. Finally, an empirical study is presented that provides support for specific parts of the theoretical framework.

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 12.1) (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 (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 and of 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 this purpose. The next section will explore 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 consist of symbols and are powerful in expressing abstract knowledge. Pictorial representations consist of icons 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). In addition, they can be used for clarification and elaboration of learners' own conceptual understanding. The process of constructing an external representation and interacting with it may foster learners' understanding, especially if the representation has a high level of sophistication (i.e., many interrelations). Therefore, self-constructing external representations can be 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 external representations might promote organisation and integration processes that foster the development of mental models. This implies that constructing external representations may enhance cognitive load that is beneficial for learning.

A well-known example of self-constructing external representations is taking notes. The overall effects of note taking on learning are positive (cf., Kiewra, 1985; Kobayashi, 2005). 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). 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 for activating prior knowledge in the science domain 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. It is important to emphasise here that external representations can differ in their level of sophistication on a continuum from low to high sophistication. Representations of low sophistication consist of simple pictures or brief notes with *few interrelations* that primarily help to *activate* possibly relevant knowledge by *offloading* memory. High-sophistication external representations are more elaborated pictures and notes that support learners to *activate* their prior knowledge *and construct* this knowledge by establishing *many interrelations*. These representations help learners to *elaborate* on their prior knowledge. In this chapter, the focus is on low-sophistication 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, low-sophistication 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 high-sophistication external representation.

Prompting prior knowledge activation

Low-sophistication external representations could be used to *prompt* prior knowledge activation (see arrow (b) in Figure 12.1). Learners could be provided with an external representation of low sophistication and asked to activate their prior knowledge about a specific topic using this representation. Learners' understanding of the organisation and functioning of objects, events, or activities (e.g., the structure of the circulatory system and the functioning of the heart) is an important part of science learning (Chi, de Leeuw, Chiu, & LaVancher, 1994). 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).

Structural and causal models are important for elaborating and refining knowledge in the science domain. Because pictures and animations correspond on a one-to-one basis to the subject they represent and are informationally complete (Schnotz, 2005), they might be better able to represent these kinds of models than verbal representations. Therefore, low-sophistication pictorial representations are expected to be more suitable to prompt prior knowledge activation. More specifically, pictures may be very useful to illustrate how a domain is organised in space, whereas animations may be very useful for illustrating how changes in one component affect changes in other components. This would imply that pictures might be most suitable for activating structural models and animations for activating causal models. It is important to emphasise here that only pictorial representations of low sophistication are considered suitable for prompting prior knowledge activation. Although these representations contain more information and are thus more sophisticated than verbal representations, they do not contain any labels or additional explanative text. However, more sophisticated pictorial representations do contain accompanying text and thus convey more information. This implies that these representations are more susceptible for deducing information from, which may interfere with prior knowledge activation.

Reinforcing prior knowledge activation

Low-sophistication 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 low-sophistication representation of their prior knowledge (see arrow (c) in Figure 12.1). 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 (Van Merriënboer & Sweller, 2005).

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 relate these concepts to one another without having to keep all concepts active in working memory. This will facilitate the activation process by reducing the load imposed on working memory during prior knowledge activation (see arrow (d) in Figure 12.1). 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 the learner, 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 low-sophistication external representations might be closely intertwined.

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

In prior knowledge activation, low-sophistication external representations might serve as a prompt to activate prior knowledge and reinforce the activation process. However, the effects of external representations in prior knowledge activation might be mediated by learners' level of prior domain knowledge. If learners' prior domain knowledge is limited, low-sophistication external representations may be less effective in prompting correct and relevant prior knowledge than if learners possess more prior knowledge or more elaborated prior knowledge (see arrow (e) in Figure 12.1). Although pictorial representations might be more suitable to prompt prior knowledge activation than verbal representations for all learners, the effectiveness of pictures and animations as prompts might also depend on learners' level of prior knowledge. Pictures may be very useful for activating structural models and animations for activating causal models. Before learners are able to build causal models, they need to possess some knowledge about how the domain is organised. Learners with relatively limited prior knowledge might possess knowledge about how the domain is structured but do not yet know how changes in one component result in changes in other components. For example, they know that the heart consists of atria, ventricles, and valves, but they do not yet know that if the ventricles contract the valves between atria and ventricles close. Animations might therefore be less beneficial for learners with limited prior knowledge, because they do not yet possess the knowledge that is triggered by the animations. For learners with high levels of prior knowledge who possess sophisticated structural *and* causal models, animations might be more effective than pictures, because they prompt both structural and causal knowledge.

The reinforcing effect of low-sophistication external representations may also be mediated by learners' level of prior knowledge (see arrow (f) in Figure 12.1). If learners have limited prior domain knowledge, it may be more difficult to self-construct a low-sophistication external representation which, in turn, might influence the beneficial offloading effect of note taking. 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 an external representation by taking notes, because they cannot distinguish relevant from irrelevant concepts or draw relations between concepts (Anderson, 1977). Therefore, self-constructing low-sophistication external representations is not expected to have beneficial offloading effects on working memory for learners who have only limited prior domain knowledge.

In sum, as the framework presented in Figure 12.1 illustrates, low-sophistication external representations are assumed to play different roles in prior knowledge activation. They can be used to prompt prior knowledge activation and they can be used to reinforce the activation process. If low-sophistication external representations are used to *prompt* prior knowledge activation, the representation is *provided* to learners and preferably *pictorial* because these representations may be more suitable to represent and activate structural and causal models that are important for learning in the science domain. Low-sophistication external representations are also assumed to *reinforce* the activation process. If learners *self-construct* a low-sophistication external representation of their prior knowledge by means of taking notes, the activation process is *facilitated* by reducing the load imposed on working memory. In addition, the effects of low-sophistication external representations are expected to be mediated by learners' *level of prior knowledge*. The prompting and reinforcing effects of external representations in prior knowledge activation are assumed to be stronger for learners who already possess sufficient prior domain knowledge.

A study by Wetzels, Kester, and van Merriënboer (2009) provided support for the mechanism of reinforcing prior knowledge activation (see the bottom part of Figure 12.1). This study investigated the effects of note taking during prior knowledge activation on learning depending on learners' level of prior knowledge. High school students completed a prior knowledge test about the circulatory system (i.e., the structure of the circulatory system and the functioning of the heart). Students were assigned to a low-prior knowledge or a high-prior knowledge group based on the median score of the prior knowledge test.

About one week later, the experimental session took place. Before working on tasks about the circulatory system, students activated their prior knowledge prompted by two prior knowledge activation pictures that represented (a) the structure of the circulatory system and (b) the functioning of the heart. Because the same prompts were used for all students, the prompting effect was not investigated in this study. First, students were provided with the picture representing the structure of the circulatory system and encouraged to bring to mind (i.e., mobilise) all knowledge they had about how blood flows through the body. Think-aloud protocols were recorded to check what knowledge was being activated and whether this knowledge was correct. Subsequently, students worked on learning tasks about this topic. Students were, for example, given the following problem that had to be solved: ‘*A child cuts itself in its finger with a piece of glass resulting in bacteria entering the blood stream. What way do the bacteria travel through the circulatory system before they reach the kidneys?*’

After activating prior knowledge about the structure of the circulatory system and working on tasks about this topic, students activated their prior knowledge about the functioning of the heart. The picture illustrated in Figure 12.2 was used to activate students’ causal model of heart functioning. Students were provided with this picture and encouraged to bring to mind all knowledge they had about the electrical system and the functioning of the heart. Again, think-aloud protocols were recorded. Subsequently, students worked on learning tasks about this more refined aspect of the circulatory system. An example of a learning task in this context was: ‘*How does the electrical system of the heart work?*’ Half of the participants was allowed to externally represent their prior knowledge by means of taking notes while activating their prior knowledge, whereas the other half was not allowed to take notes.

[INSERT FIGURE 12.2 ABOUT HERE]

Finally, students worked on a number of transfer tasks concerning the structure of the circulatory system and the functioning of the heart. These tasks provided an indication of how well students understood what they had learned during the learning phase. More specifically, transfer tasks assessed whether students were able to transfer the principles (e.g., blood flows from the atria to the ventricles) they had learned while working on the learning tasks. Students had to apply these principles both in familiar situations (e.g., blood flow in a healthy individual) as well as in unfamiliar situations (e.g., blood flow in a child with a congenital heart defect). Students who took notes while activating their prior knowledge were not allowed to review or elaborate on their notes while working on the learning and transfer tasks. Students were also not allowed to take notes while working on the tasks.

Learning effectiveness and efficiency were measured by means of performance, mental effort, and mental efficiency. Mental effort represented the amount of effort students had to invest to solve a task as rated on a subjective rating scale. Mental efficiency was a combination of transfer test performance and invested mental effort during transfer. A high efficiency indicated a transfer test performance that was higher than expected based on the amount of invested mental effort during the transfer phase, whereas a low efficiency indicated a transfer test performance that was lower than expected based on invested mental effort (Paas & van Merriënboer, 1993). So, mental efficiency is a learning measure that provides information that goes beyond information provided by performance and mental effort measures alone.

Results showed that the efficiency of note taking (i.e., the reinforcing effect of external representations) during prior knowledge activation was influenced by the amount of prior domain knowledge learners already possessed. For learners with higher levels of prior knowledge about the circulatory system, note taking lowered mental effort while working on transfer tasks and increased mental efficiency during transfer. For learners with lower levels of prior knowledge, note taking yielded the opposite effect on mental effort and efficiency during the transfer phase. Figure 12.3 illustrates the interaction effect between level of prior knowledge and note taking on mental effort (A) and mental efficiency (B) during the transfer phase.

[INSERT FIGURE 12.3 A&B ABOUT HERE]

By externally representing their prior knowledge, learners with higher levels of prior domain knowledge are enabled to activate concepts and relate these concepts to one another without having to keep them active in working memory. The resulting low-sophistication external representation reduces the load imposed on working memory while activating prior knowledge. This offloading effect of taking notes facilitates the activation process which enhances learning for high-prior knowledge learners. However, 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 low-sophistication 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.

Surprisingly, high-prior knowledge learners did not construct a more sophisticated external representation of their prior knowledge than low-prior knowledge learners. The number of (correct) relations described in the notes was very low, independently of learners' level of prior knowledge. This is consistent with Kiewra's (1985) observation that relational note taking is difficult for learners.

There was some support for the assumption that the prompting effect of external representations is mediated by learners' level of prior knowledge. Learners with higher levels of prior knowledge generated more concepts, more relations between activated concepts, and more correct relations in the think-aloud protocols than learners with lower levels of prior knowledge. High prior knowledge learners also generated more concepts in their notes compared to low prior knowledge learners. These results seem to suggest that pictorial representations prompt more elaborated and more organised knowledge in learners with more prior domain knowledge. In sum, both the prompting and the reinforcing effects of external representations seem to be influenced by how much prior domain knowledge learners already possess.

General discussion

In this chapter, a theoretical framework was outlined that described the effects of low-sophistication external representations during prior knowledge activation in the science domain. First, it was described that low-sophistication 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; pictorial representations are assumed to be more suitable for representing and prompting structural and causal models that are important for science learning. Second, low-sophistication external representations were considered to reinforce the activation process. By self-constructing an external representation of learners' prior knowledge, 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. More specifically, these effects were assumed to be more pronounced for learners with relatively higher levels of prior domain knowledge. Finally, the mechanism for reinforcing prior knowledge activation and the influence of learners' prior knowledge on the reinforcing effect of low-sophistication external representations was supported by the results of an empirical study.

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 are 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 it 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.

Despite these limitations, the framework provides interesting insights into the various variables that may be involved in prior knowledge activation. In addition, the theoretical framework broadens the note taking research. The traditional note taking research focused on the encoding and the external storage effect of note taking (Di Vesta & Gray, 1972). 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. So, the encoding effect represents the effects of note taking *during* learning. The external storage function signifies that having notes available for review after attending a lecture or reading a text is beneficial for learning. So, the external storage function represents the effects of note taking *after* learning. However, in this chapter, the effects of note taking *before* learning are investigated. Learners take notes while activating their prior knowledge before they are provided with learning materials.

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 represent 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. They build a high-sophistication external representation 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.

Future research should focus on several aspects of the framework. The first line of research could focus on the prompting effect of external representations and how this is mediated by learners' level of prior knowledge. It would be interesting to explore whether and under which circumstances pictures and animations are more efficient in prompting prior knowledge activation. Are pictures indeed more suitable for activating structural models and animations for activating causal models? And how is the effectiveness of pictures and animations influenced by learners' prior knowledge? When investigating the prompting effect of pictures and animations, the possibility that learners learn from an external representation should be considered. Even if low-sophistication 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. Therefore, it should be investigated how genuine prior knowledge activation can be discerned from information that is deduced from pictures and animations.

A second line of research is related to self-constructing external representations by taking notes. More specifically, self-constructing external representations might not only have reinforcing effects but also serve as a prompt for prior knowledge activation. Prior knowledge might initially be prompted by the provided pictorial representation with further prompts resulting both from the provided pictorial representation and the self-constructed representation. The extent in which self-constructing an external representation may serve as a prompt for further prior knowledge activation may again depend on learners' level of prior knowledge.

Although this seems a very plausible and interesting idea, it might be quite difficult to disentangle the prompting effect resulting from the provided pictorial representation and the prompt that results from the self-constructed representation. This implies that it is also important to explore if and how these prompting effects could be differentiated.

A third line of research might further investigate the influence of learners' level of prior knowledge on the reinforcing effect of self-constructed external representations. The study of Wetzels et al. (2009) showed that externally representing prior knowledge by means of taking notes was more beneficial for learners with sufficient prior knowledge. However, all participants in this study were high school students. So, all participants might have been on the low end of the expertise continuum. The question is how increasing and stronger differentiated levels of prior knowledge affect the reinforcing effect of external representations. Is this effect getting stronger for learners who are on the higher end of the expertise continuum (e.g., medical students)? Or perhaps, self-constructing external representations has no beneficial offloading effects on working memory for learners with higher levels of prior knowledge because these learners may easily hold a representation of their prior knowledge in working memory without overloading it. This might imply that these learners will not benefit from self-constructing external representations and that the reinforcing effect is not as strong as for learners with intermediate levels of prior knowledge. These issues could be tackled in future research.

A practical implication that follows from the presented framework is related to teaching practices. Encouraging learners to externally represent their prior knowledge might facilitate the activation process and learning, but only for learners who already have sufficient prior domain knowledge. For learners with too little prior knowledge, self-constructing external representations might not have any beneficial offloading effects on working memory. Therefore, teachers should take their students' level of prior knowledge into account when asking them to self-construct a low-sophistication external representation of their prior knowledge.

In sum, the presented framework provides more insights into how low-sophistication external representations can be used to support the process of prior knowledge activation and how this is influenced by learners' level of prior knowledge. However, future research is necessary to further elaborate and refine the framework.

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Figure captions

Figure 12.1. Theoretical framework illustrating the use of low-sophistication external representations in prior knowledge activation.

Figure 12.2. Picture used to activate prior knowledge about the functioning of the heart

Figure 12.3. Interaction effect between level of prior knowledge and note taking for mental effort (A) and mental efficiency (B) during transfer

Figure 12.1

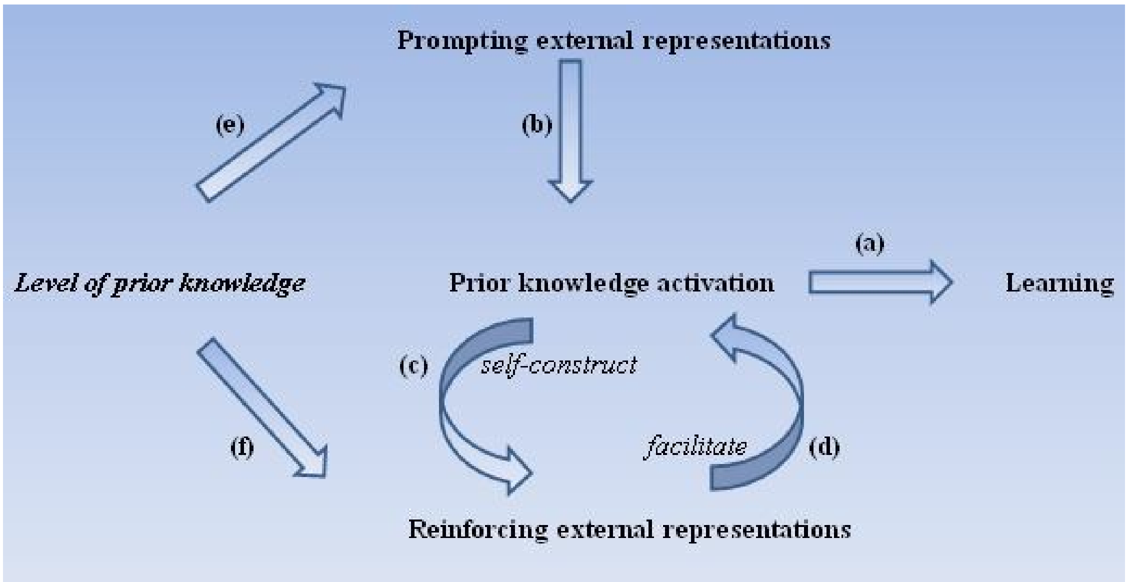
Prompting external representations
(e)
(b)
(a)
Level of prior knowledge
Prior knowledge activation
Learning
(c)
self-construct
(f)
facilitate
(d)
Reinforcing external representations

Figure 12.2

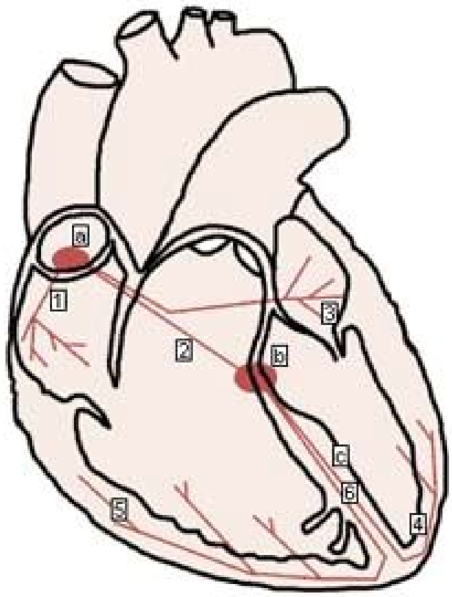

Figure 12.3

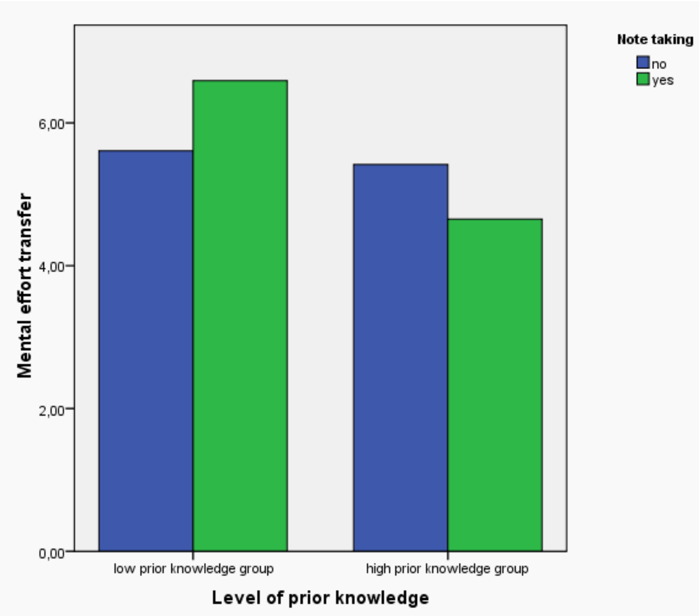

Figure 12.3A

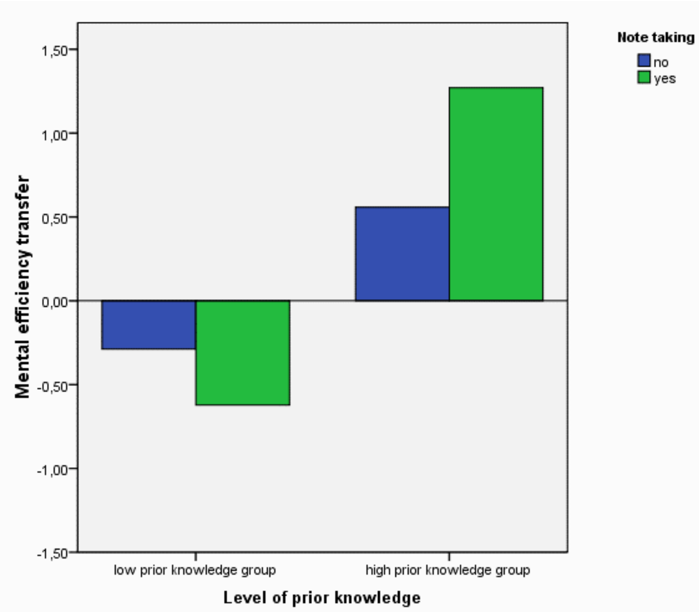

Figure 12.3B