Improving students' science text comprehension through metacognitive self-regulation when applying learning strategies

Metacognition and Learning

December 2015, Volume 10, Issue 3, pp 313–346 | Cite as

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Article
First Online: 23 January 2015

Abstract

In three experiments, students were trained to use strategies for learning from scientific texts: text highlighting (Experiment 1), knowledge mapping (Experiment 2), and visualizing (Experiment 3). Each experiment compared a control condition, cognitive strategy training, and a combined cognitive strategy plus metacognitive self-regulation training with a specific focus on the quality of cognitive strategy application. After the training, students applied the learning strategies as they studied scientific texts. Across experiments, the results indicated that the self-regulation component of the training helped the students to overcome the lack of efficacy of the cognitive strategy only training when it was not effective by itself: The highlighting-only group was outperformed by the control group ($d = -1.25$), but the combined highlighting-plus-self-regulation training reduced this negative effect ($d = -0.21$). The mapping-only group performed as well as the control group ($d = -0.12$), but the combined mapping-plus-self-regulation group outperformed the control group ($d = 0.76$). The visualizing-only group outperformed the control group ($d = 0.72$) as did the combined visualizing-plus-self-regulation group ($d = 0.78$). Results suggest that cognitive learning strategies differ in their potential to induce deep versus surface processing of text contents. In addition, the metacognitive self-regulation component of the training enhanced students' performance when the cognitive strategy training was not effective by itself.

Keywords

Self-regulated learning Learning strategy Quality Strategy training Metacognition Text comprehension

This article focuses on the question of whether the comprehension of scientific texts can be improved by fostering the quality of students' learning strategy application. By comprehension, we mean higher level comprehension that requires the reader to draw inferences, to link ideas coherently, and to build connections between newly acquired knowledge and prior knowledge (Kintsch 1998). We investigated whether students could learn to monitor and to regulate the quality of their strategy use and—as a consequence—to apply learning strategies more effectively. We tested the effects of training in quality-based monitoring and regulation with three different cognitive strategies: highlighting (Experiment 1), mapping (Experiment 2), and visualizing (Experiment 3).

The importance of the quality of students' strategy application

Models of self-regulated learning propose that students can control their learning process by applying various cognitive, metacognitive, and motivational-emotional strategies (Bandura 1986; Boekaerts 2002; Pintrich 2000; Schunk and Usher 2011; Winne 2011; Zimmerman 2008). In this paper, we focus on the effects of a combination of cognitive and metacognitive strategies. Researchers propose that learners can control their cognitive processing by applying metacognitive strategies such as planning, monitoring, and regulating their learning (Dignath and Büttner 2008; Nelson and Narens 1994; Pintrich 2000; Winne 2011; Zimmerman 2008). There is also consensus that these cognitive and metacognitive processes interact in different ways (Azevedo and Witherspoon 2009) and together constitute the components of the feedback loop of self-regulated learning. For the feedback loop to operate, students should set goals for their learning—usually at the beginning of a learning phase—and then select and apply cognitive strategies in order to reach their goals. At the same time, they should monitor their performance, assess their progress toward their goals, and adjust their processing accordingly. As discussed in self-regulation theories these can be simple adjustments such as rereading a paragraph or broader adjustments such as changing the present cognitive strategy for a more appropriate strategy. Imagine, for example, a student named Linda, who is reading a chapter in a textbook on chemical bonds. Linda aims to read the chapter with the goal of understanding the material and applies a highlighting strategy to guide her cognitive processing. Every once in a while, she stops and monitors her progress toward her goal. This monitoring process provides her with information about her emerging understanding of the topic. Accordingly, Linda reacts to her judgments. For example, when she senses that she does not clearly understand the topic, she may decide to read the text again or to change her learning strategy and study the text using a mapping strategy instead of the highlighting strategy. Although this is an example in which a student exerts control over her cognitive processing, the effectiveness of this type of regulation of one’s learning may not depend solely on changing one’s cognitive strategy or on rereading the text. We propose that the quality of the particular cognitive strategy that is applied is also an important factor. A learner might not reach the desired learning goal because he or she does not apply the strategy in an effective way – although the strategy itself is appropriate for the desired goal in question.

Imagine a student who applies the mapping strategy in an ineffective way by constructing a map that is composed of unimportant concepts and relations. Consequently, the students’ map will be quite confusing and will not help him or her to organize and structure the text paragraph (see the example in Fig. 1, left side). Thus, the primary function of a mapping strategy (i.e., to foster the organization of the learning material) will not be fulfilled. By contrast, imagine another student who uses the strategy in an effective way by focusing on relevant concepts and their relations and thereby creates a clearly structured, concise, and coherent map (see Fig. 1, right side). If we asked both of these students whether they applied the mapping strategy, both would tell us that they created a knowledge map. However, only the latter student would be expected to benefit from such a strategy application because this student used the strategy in a high-quality (i.e., effective) way. This quality-specific aspect of learning strategy application has not yet received much attention within the learning strategy literature but is, we propose, relevant for strategy instruction and learning strategy training (Glogger et al. 2012; Leutner et al. 2007).

Fig. 1

Two examples of a knowledge map created by high school students in Experiment 2 (left side: fuzzy map; right side: clear map)

What are the criteria for high-quality strategy use? A learning strategy is applied in a high-quality manner if the specific goals of the strategy are fulfilled by its use. The goals of a strategy, in turn, depend on the main purpose or function of the particular strategy. For example, the main function of the mapping strategy is to help the learner to organize and structure his or her learning materials. The specific goals correspond to that function and therefore involve identifying important concepts in the text, specifying their relations, and arranging them in a clear and meaningful way (Dansereau et al. 1979; O’Donnell et al. 2002; Weinstein and Mayer 1986).

When a student's attention is explicitly directed toward monitoring the quality of strategy application, that student is drawn to the referential contents (i.e., the situation, objects, and elements that are explained in the text). The reason for this connection between the quality of strategy application and the referential contents is that the quality of strategy use can be assessed only with respect to the particular referential contents. For example, when a student wants to assess the quality of the map he or she created, the student is required to reconsider the referential contents of the text because the quality of the map depends on whether it reflects the basic relations between the referential objects and elements. If the student reflects on whether a "type-part arrow" would correctly represent the relation between two objects, he or she must consider whether one object is really a part of the other object. Therefore, we suggest that the quality of strategy application cannot be assessed by considering only the surface features of a text or by referring only to a text-based representation (Kintsch 1998).

Empirical evidence indicates that students often do not use strategies in a high-quality way (Glogger et al. 2012; Simpson et al. 1994). This is particularly noteworthy as the quality of strategy use is related to learning performance. Simpson et al. (1994), for example, reported strong correlations between the quality of verbal elaborations on key ideas from a text on linguistics and text comprehension in a sample of high-risk college students. The quality of these elaborations was based on indicators such as the extent to which they included generalizations or appropriate personal examples.

Leopold et al. (2013) and Schwamborn et al. (2010) found that the quality of self-generated drawings of high school students (constructed while reading a science text) was strongly related to their comprehension and transfer performance. Similarly, Glogger et al. (2012) found substantial correlations between the quality of learning strategies (assessed by learning journals) and the learning performance of high school students in mathematics and biology classes: The higher the quality of students' organization and elaborations in their learning journals, the better was their learning performance on tests of conceptual and procedural knowledge.

Martin and Pressley (1991) used an experimental approach and investigated the effects of "why" questions for fostering the elaboration of text concepts. They varied the questions with respect to their focus on to-be-learned text contents. Results showed that highly specific "why" questions facilitated recall most, whereas unspecific questions did not facilitate recall at all. Thus, the quality of the "why" questions was an important factor for recall performance.

In sum these results suggest that learning strategy research should focus not only on the learning strategies themselves, but also on the quality of strategy application. Therefore, the goal of the present set of experiments was to investigate whether a learning strategy training that was focused not only on teaching students to apply a learning strategy but also on improving the quality of strategy application would affect comprehension performance.

A quality-oriented training approach

In the light of the relevance of the quality of strategy application, a pertinent question is: How can students be trained to apply strategies in a high-quality way? The basic idea of the training approach presented in this paper is to teach students not only declarative and procedural knowledge about cognitive learning strategies (i.e., how to highlight important text passages, how to draw a concept map, or how to visualize text contents), but also to teach them how to engage in high-quality strategy use by means of metacognitive self-regulation strategies (Leutner et al. 2007; Schreiber 1998). This type of quality-based monitoring involves metacognitive processing. The advantage of metacognitive strategies is that they operate on a higher level than cognitive strategies and can therefore modify and regulate cognitive strategy application (Nelson and Narens 1994; Pintrich 2000; Winne 2011). Consequently, metacognitive strategies can be utilized to regulate the quality of the application of a particular cognitive strategy. Teaching students to monitor and regulate the quality of their cognitive strategy use was expected to be effective in terms of improving the quality of their cognitive strategy use and, thus, their learning performance.

As illustrated in Fig. 2, a distinction can be made between the "what" and the "how" of self-regulation. The "what" of self-regulation refers to cognitive strategies such as highlighting, mapping, and visualizing. It comprises declarative, procedural, and conditional knowledge of the strategy in question (Paris et al. 1983). The "how" of self-regulation refers to how effectively the particular cognitive strategy is applied. Metacognitive strategies can help the learner to apply the cognitive strategies more effectively. We adopted the metacognitive strategies of self-observation, self-assessment, and reaction from Bandura (1986) and implemented them according to the approach proposed by Schreiber (1998). These metacognitive strategies are aimed at monitoring and controlling the quality of a specific strategy's use, and the assessment of this quality depends on whether the particular goal of that strategy is achieved. The quality of a student's strategy use can be indicated by traces that were produced while the student applied the strategy. Winne and Perry (2000) describe traces as "observable indicators about cognition that students create as they engage with a task" (p. 551). In order to enhance the quality of highlighting, for example, students can be taught (a) to self-observe and self-assess whether they highlighted only the really important concepts, (b) to react and adjust their strategy by reconsidering which concepts are important, and (c) to erase the highlighting of unimportant concepts. Cognitive learning strategies can thus be applied in a more focused and goal-oriented way.

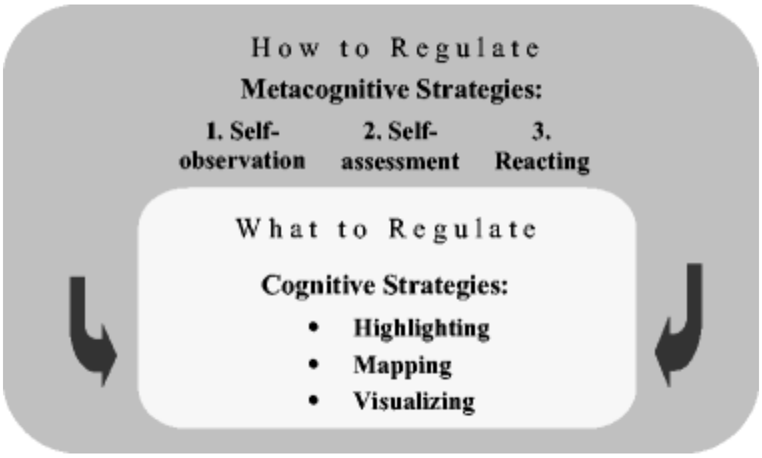

Fig. 2

A training approach for fostering self-regulated learning (adapted from Schreiber 1998)

One main advantage of such an approach is that the focus of the feedback loop is shifted from monitoring text comprehension and learning performance in general to monitoring and regulating the processing strategy itself. By explicitly drawing students' attention to the quality of their processing strategy, this approach requires the students to adopt specific standards on which to base their assessments. For example, when students are asked to consider and assess the quality of their maps, they are asked to evaluate whether they have really identified the important concepts in the text, clarified the relations between the concepts, and finally arranged the concepts in a clear and concise way. These specific standards may be easier to monitor and to control than standards that are focused on general performance per se (Wiley et al. 2005).

However, this benefit has its price. In quality-based monitoring, the feedback loop is based on the particular strategy that is applied. Thus, the metacognitive system and the metacognitive processes operate only in relation to the standards of that particular strategy. Therefore, they are specific to the individual strategy, and the quality of strategy application can be assessed only within the scope of the particular strategy in question. This is important because strategies vary in the extent to which they require deeper processing (Dunlosky et al. 2013) and foster mental model building (e.g., Leopold and Leutner 2012). Thus, different learning strategies can be expected to foster text comprehension to different degrees. For example, highlighting strategies require the students to work very closely with the text. It is therefore likely that these strategies will draw the students' attention toward the text itself rather than toward the referential contents. Mapping strategies require the students to restructure and reorganize the text. Thus, to some extent, the students have to depart from the original wording of the text. By contrast, visualizing strategies require the students to translate or transform the textual input into a pictorial representation; thus, to do so, the students must clearly go beyond the text.

The purpose of the following set of experiments was to test the effects of training in quality-oriented monitoring and regulation for the three different strategies: highlighting, mapping, and visualizing. We expected cognitive strategy training to benefit from including metacognitive self-regulation strategies that focused on the *quality* of cognitive strategy use. In other words, it is not sufficient to teach students the steps of a cognitive learning strategy, but rather, effective strategy use requires them to self-regulate the quality of their cognitive strategy use. Consequently, high-quality strategy use was expected to improve text comprehension.

Experiment 1: highlighting strategy

Text highlighting is a cognitive strategy that supports the selection function of active information processing because learners must concentrate on identifying the main ideas of a text and on selecting text information with respect to its significance (Mayer 1996; Weinstein and Mayer 1986). However, this strategy encourages students to focus more on individual concepts than on how these concepts might be related to each other. In addition, during strategy application, when highlighting, the learner's attention is naturally drawn toward the text itself rather than toward "what the text is about" (Glenberg et al. 1987, p. 70.) We therefore expected that the highlighting strategy's potential to foster deep comprehension, which is based on the representation of the situation described by the text, would be rather low.

Empirical evidence has shown that highlighting is not necessarily an effective study method compared with simply reading a text (see the reviews by Dunlosky et al. 2013; Hartley et al. 1980). From their literature review on underlining, Dunlosky et al. (2013) concluded: "We rate highlighting and underlining as having low utility" (p. 21), and Hartley et al. (1980) concluded "that few studies, if any, provide clear-cut support for the effectiveness of underlining" (p. 218). Furthermore, most studies in this area have focused on recall performance or text recognition and did not find an advantage for highlighting compared with simply reading a text (e.g., Fowler and Barker 1974; Marxen 1996). However, Peterson (1992) investigated the effects of highlighting on the retention of facts and on comprehension performance that was based on inferential questions. Peterson found no differences between underliners and non-underliners (simply reading) for factual questions, but surprisingly found that non-underliners outperformed underliners on inferential questions. How can these results be explained?

We propose that it is important to take into account the quality of strategy use. The selection function of the highlighting strategy is fulfilled only when students focus their attention on higher level information and underline only a few really important concepts. Although underlining is a very popular strategy, its application is often less than optimal because students do not spontaneously attend to higher level information and almost always underline too much. For example, in Peterson's (1992) study, the majority of students (78 %) reported typically underlining between one quarter and half of a text. In Dumke and Schäfer's (1986) study, students underlined nearly one third of the text. These results indicate that students do not underline discriminately. When students were instructed to underline only one sentence per paragraph, the strategy proved to be more successful (Rickards and August 1975). Likewise, in Leutner et al.'s (2007) study, students trained in highlighting outperformed a control group. Students trained in highlighting *and* in the self-regulation of highlighting outperformed both the highlighting-only group and the control group. Students can thus benefit from high-quality highlighting strategies. However, the studies described above tested for recall of text information (except Peterson 1992). Therefore, in Experiment 1, we tested whether students could be trained to highlight important information and to self-regulate the quality of their strategy use and whether this combination of highlighting and self-regulation training would affect their comprehension performance relative to highlighting-only training and no training (control group).

Hypotheses about strategy knowledge

After students had completed the training program, we first examined whether students had acquired knowledge about the highlighting and self-regulation strategies because declarative strategy knowledge is regarded as a general prerequisite for successful strategy application (Pressley et al. 1989). We predicted that the highlighting-only group and the highlighting-plus-regulation group would not differ in their knowledge of highlighting because both groups had received the highlighting training. On the other hand, we predicted that the highlighting-plus-regulation group would outperform the highlighting-only group on knowledge of self-regulation because only the highlighting-plus-regulation group had received the regulation training.

Hypotheses about strategy application

Besides declarative strategy knowledge, students have to know how to apply the strategies (Pressley et al. 1989). To assess strategy application, we asked the students to self-assess their strategy use, and we analyzed the traces the students produced in the text (i.e., their highlighting). We expected that both the highlighting-only group and the highlighting-plus-regulation group would report more selections of main ideas than the control group. We expected that the highlighting-plus-regulation group would show qualitatively better highlighting than the highlighting-only group.

Hypotheses about comprehension

We expected that the highlighting-plus-regulation group would comprehend the text better than the highlighting-only group or the control group. However, the available research on text highlighting did not allow predictions to be made about whether or not the highlighting-only group would outperform the control group in text comprehension.

Method

Participants and design

The participants were 47 Grade-10 students in a senior high school. The study had a between-subjects design with type of strategy training (highlighting plus regulation, highlighting only, and control) as a single factor. Prior knowledge of text contents was used as a covariate to focus on the knowledge acquired during the learning phase. Within their classes, students were randomly assigned to one of three experimental groups. One student attended only the training phase but not the test phase and was therefore excluded. The highlighting-plus-regulation group comprised 14 students, the highlighting-only group 15 students, and the control group 17 students. Their mean age was 15.52 years ($SD = 0.51$), and the percentage of female students was 60.9 %.

Materials

The materials consisted of the training program and the learning and testing materials.

The training program

The training program consisted of two components. First, in a highlighting example, each individual step of the highlighting strategy was presented to provide an overview of the strategy. Second, a highlighting training component gradually elaborated each step of the strategy and had students practice them (highlighting training). The highlighting-plus-regulation version of the training program added a self-regulation example to the highlighting example component and a self-regulation strategy section to the highlighting training component. The instructional design and the sequencing of the training program followed the simple-to-complex pattern proposed by Reigeluth (1999). Every student was given a training booklet containing notes and diagrams (symbols, comic figures) summarizing the information presented verbally by a trainer, as well as exercises and reading passages providing opportunities to apply the highlighting strategy (see Fig. 3).

Fig. 3

Example of the highlighting training from the training booklet

The highlighting example was based on a real-world situation: A fictitious student named Daniel encounters problems while preparing for a biology test. He feels overwhelmed by the amount of material and decides to use a highlighting strategy to discriminate between important and less important information. He works through the first chapter of his course book, paragraph by paragraph, applying the following strategy steps: (1) read a paragraph, (2) circle the words denoting the main idea of the paragraph, (3) reread the paragraph and highlight additional important information, (4) use side notes to specify the function of the paragraph (e.g., "definition," "example," etc.). The four strategy steps were derived from Dumke and Schäfer (1986) and Leutner et al. (2007).

Students in the highlighting-plus-regulation group additionally studied the self-regulation example: Daniel leans back in his chair and reflects on his strategic processing. He self-observes his performance in applying the highlighting strategy: How did I apply the highlighting strategy? Which steps did I perform? He self-assesses whether he succeeded in discriminating between important and unimportant information (e.g., Have I identified the main idea in each paragraph?). As a reaction to this self-assessment, he decides to revise his highlighting.

In the highlighting strategy component of the training program, the individual steps of the strategy are gradually elaborated and enriched with additional information, explanations, and exercises. Learners are first informed of the goal of the highlighting strategy: to help them identify important text information. The presentation and explanation of the steps of the strategy closely parallel the example in order to foster the learners' declarative knowledge of highlighting. For example, students are taught that the main idea Daniel circled could be viewed as the headline of the paragraph. The main idea can be summarized in a few words. A visual example is presented in which the main idea is compared to a central point to which all other important concepts are attached. Students are further taught that authors use signals in a text to indicate the main idea with phrases such as: "This paragraph is about …." Students are administered practice tasks with multiple-choice and classification items to test their declarative strategy knowledge (e.g., "Which types of marks are called verbal marks?") The trainer provides feedback for each task. To foster procedural knowledge, the trainer models the application of the steps based on a typical passage from a biology textbook; the trainer "thinks out loud" to help students follow his or her mental processes. Students are then asked to apply the strategy increasingly autonomously, with the trainer providing appropriate feedback at each step. This approach of scaffolding strategy use and gradually fading out the trainer's support helps students to learn to apply the strategy by themselves. Finally, students are asked to apply the steps of the highlighting strategy autonomously while reading a science text passage. The passages used in the training pertained to the topics of diffusion and osmosis. Feedback is provided after all four strategy steps have been performed. Furthermore, students are informed about when and why to use the highlighting strategy—that is, they are given conditional knowledge of strategy use.

In the self-regulation component, the steps of the self-regulation strategy are presented, explained, and practiced. Students learn that self-regulated learning means viewing their learning from an external perspective—that is, self-observing and self-assessing how they apply the highlighting strategy and reacting appropriately. The first step, self-observation, is intended to sensitize the learner to his or her own strategic actions while reading a text and highlighting parts of it. The second step, self-assessment, is intended to help the learner to judge whether he or she has applied the strategy appropriately and, for example, highlighted the main idea of the paragraph. The third step, reaction, is intended to help the learner to adjust his or her strategy use, for instance, by erasing the highlighting of unimportant concepts. For practice, students are given exercises that require them to reflect, like Daniel in the example, on the approach they took in the previous highlighting training session. Furthermore, they are asked to reflect on how well they applied the highlighting strategy and to write down the results of their reflections. Finally, students consider reactions that are appropriate when all the important information has been highlighted (e.g., "reward oneself") or when too much unimportant information has been highlighted (e.g., "check highlighting"). This part of the training program closes with a summary and with exercises designed to revise and consolidate students' declarative knowledge of the strategy steps. The training was conducted by university students who had nearly completed their teacher training and had already obtained some teaching experience. These experimenters were trained by the first author on how to conduct the highlighting training and the self-regulation training. The experimenter training included various practice exercises including constructive feedback. The experimenters also received a script in which each step, procedure, and the available time was described.

Control group

Students in the control group participated in an English lesson in which they read, presented, and discussed short texts about the countries of the United Kingdom and performed grammar and writing exercises. An experimenter who had nearly completed his teacher training taught the control group. We asked a university student rather than a regular teacher from the school to teach the control group in order to ensure that the control condition would be similar to the training conditions. The reason was to prevent effects that are due to merely participating in a study, an act that is different from the students' normal school day and therefore has the potential to enhance their interest and motivation (Hawthorne effect).

Learning and testing materials

The materials consisted of (a) a strategy knowledge test assessing knowledge of the highlighting strategy and the self-regulation strategy, (b) a science text about water molecules, (c) two multiple-choice comprehension tests assessing prior knowledge and text comprehension, (d) a self-report strategy questionnaire, and (e) a standardized test measuring verbal ability as a control variable.

The strategy knowledge test consisted of 14 single-choice questions with seven items measuring knowledge of the highlighting strategy (e.g., "The most important information in a paragraph is… (a) underlined, (b) written down, (c) circled") and seven items measuring knowledge of the self-regulation strategy (e.g., "How should you react to highlighting too much information? (a) write down the most important information, (b) reduce your highlighting, (c) erase your side notes") (see Appendix 2 for the complete set of items).

The science text about water molecules (1470 words) consisted of six paragraphs explaining (a) the chemical structure of water molecules, (b) the dipole character of water molecules, (c) hydrogen bonds, (d) the hydration process, (e) surface tension, and (f) the density anomaly of water.

A criterion-referenced multiple-choice test assessed comprehension of all six topics of the science text (16 items with four alternatives; Cronbach's $\alpha = 0.64$). The test was previously piloted in a larger sample with $\alpha = 0.88$ (Leopold and Leutner 2002). Example items are given in Appendix 1. These items required students to make inferences by linking information from separate sentences in the text; the answers could not be simply memorized from the text. Ten multiple-choice items covering the six topics of the science text were constructed to assess students' prior knowledge in a pretest. These items were different from the ones used to assess comprehension after studying the text.

A self-report scale was designed to measure whether students in the experimental groups reported applying the highlighting strategy with a focus on cognitive processes. After reading the science text, students were asked to rate on a 4-point scale ranging from completely agreeing to completely disagreeing whether they thought they had selected the main ideas of each paragraph. The items were: "I thought about which concepts were most important in each paragraph," "I identified the central idea in each paragraph," "I thought about which key terms would best reflect the contents of each paragraph," "I tried to summarize the information in each paragraph by identifying the underlying concept," and "When reading each paragraph, I asked myself what the main topic was about" (five items, Cronbach's $\alpha = 0.82$). The questionnaire also included other strategy scales that were not relevant to the present research questions.

A standardized intelligence test (the word fluency scale by Heller and Perleth 2000) measured verbal ability, a widely used predictor of text comprehension, as a control variable.

Procedure

The experiment was conducted in classrooms at the school. The students were randomly assigned to one of the three treatment groups. A teacher introduced the experimenters who explained the study procedure to the students. The students were informed that the study was about how students process and comprehend text and why this is important for their learning. The students were informed that all data would be anonymous but that they could receive individual feedback on their results if they wished by using a code. The students were also informed that their participation in the study was voluntary and that there would be no consequences if they did not want to participate. Students who did not wish to participate were offered the opportunity to attend a different class.

First, the students completed the pretest assessing prior knowledge of the contents covered in the science text (5 min). Subsequently, the experimental groups received highlighting-only training or highlighting-plus-regulation training, and the control group received the English lesson (90 min). To even out the learning time of the two highlighting groups, students in the highlighting-only group were given additional practice in applying the highlighting strategy to a popular science text entitled "Born Experts." After the training sessions, the strategy knowledge test was administered to the experimental groups (4 min). Students then had their regular break (10 min), after which they had 30 min to study the science text on water molecules. Students were aware that they would be tested on their comprehension of the text. The experimental groups were instructed to apply the highlighting strategy. The highlighting-plus-regulation group was additionally instructed to apply the self-regulation strategy. The control group was asked to read and comprehend the text as they would usually do it. The texts were then collected so that students' traces could be analyzed. Finally, students completed the strategy application questionnaire (10 min), the verbal ability test (5 min), and the science comprehension posttest on water molecules (10 min).

Analysis of students' highlighting

We assessed the quality of strategy use by analyzing students' highlighting. Three quality indicators were used: First, we determined the number of correct *main ideas* circled by the students. These main ideas refer to information at the highest level of importance—the theme or topic of the paragraph. Two independent raters (a science teacher and the first author) identified the main idea of each of the six paragraphs. There was 100 % interrater agreement on the six main ideas. Second, we determined the number of correctly highlighted *important concepts*. Important concepts are closely associated with the main idea but represent information at an intermediate level of importance. The two raters identified five to 11 important concepts per paragraph (depending on paragraph length) and compared their choices. Differences were discussed and resolved, resulting in 47 important concepts. Third, we determined the number of *less important pieces of information* that were highlighted. We included less important information because empirical evidence indicates that "less is more" in the context of highlighting (Dumke and Schäfer 1986; Rickards and August 1975). To this end, the pieces of information highlighted by each student were counted, and the numbers of important concepts and main ideas were subtracted from this total to provide the number of less important pieces of information.

Results

Before testing the hypotheses, we examined whether the three treatment groups differed in their verbal ability scores. No between-group differences were found, $F(2, 43) < 1$ (see Table 1 for means and standard deviations). There was a difference in the students' prior knowledge scores, $F(2, 43) = 4.05$, $p = 0.024$. A post hoc test showed that the highlighting-plus-regulation group scored somewhat higher than the control group ($p = 0.02$). All other differences were not significant. Prior knowledge was included as a covariate in the analyses of the trace indicators and learning performance.

Table 1

Means (standard deviations) of dependent variables in the highlighting experiment

	Experimental condition		
	Control	**Highlighting only**	**Highlighting plus self-regulation**
Knowledge			
About highlighting		3.93 (0.96)	4.50 (0.94)
About self-regulation		2.20 (1.15)	3.71 (1.00)
Comprehension test	43.88[a] (5.49)	37.74[a] (3.70)	42.78[a] (5.08)
	43.06[b] (5.96)	37.87[b] (4.31)	43.64[b] (4.75)
Strategy use	2.60 (0.64)	3.41 (0.43)	3.39 (0.47)
Quality indicators			
Main ideas		5.33 (1.11)	5.00 (1.36)
Important concepts		26.93 (11.70)	23.50 (10.47)
Less important concepts		189.47 (104.44)	138.64 (101.23)
Prior knowledge	25.06 (4.16)	27.07 (3.35)	28.64 (2.73)
Verbal ability	17.00 (3.39)	17.80 (2.83)	17.50 (3.65)

Note. MSE = 23.95

[a]Adjusted for prior knowledge

[b]Unadjusted scores

(1) Did students in the strategy training groups acquire knowledge of the strategies they were trained to use?

Results of the strategy knowledge test showed that both training groups acquired knowledge of the highlighting strategy (their test performance was far above the probability of guessing) and did not differ significantly in the level of highlighting knowledge they acquired, $t(27) = 1.60$, $p = 0.121$. However, the highlighting-plus-regulation group acquired more knowledge about how to monitor and regulate their strategy use than the highlighting-only group did, $t(27) = 3.79$, $p < 0.001$, $d = 1.41$ (see Table 1 for means and standard deviations).

Did students in the highlighting-plus-regulation group understand the text contents better than students in the highlighting-only and control groups?

To examine overall differences in science comprehension test scores across experimental groups, we calculated an ANCOVA with treatment as the between-groups factor and prior knowledge as a covariate. Before performing the analysis, we tested the homogeneity of the regression as a prerequisite for the analysis of covariance. The regression slopes for predicting comprehension performance by prior knowledge did not vary across the treatment groups, $F(2, 40) = 1.91$, $p = 0.161$. The analysis of covariance revealed a statistically significant effect of prior knowledge, $F(1, 42) = 4.85$, $p = 0.033$, $MSE = 23.95$, $\eta^2 = 0.10$, and an overall effect of the treatment, $F(2, 42) = 6.81$, $p = 0.003$, $MSE = 23.95$, $\eta^2 = 0.25$ (see Table 1 for means and standard deviations). In line with our predictions, planned comparisons (Jaccard 1998, p. 12) on the adjusted means showed that the highlighting-plus-regulation group outperformed the highlighting-only group, $t(42) = 2.77$, $p = 0.008$, 95 % CI [1.48, 8.61], $d = 1.03$. However, in contrast to our predictions, the highlighting-plus-regulation group did not outperform the control group, $t(42) < 1$, 95 % CI [−2.36, 4.56], $d = -0.22$. Somewhat surprisingly, the control group outperformed the highlighting-only group, $t(42) = -3.54$, $p = 0.001$, 95 % CI [−9.55, −2.74], $d = -1.25$. Thus, the data confirmed our prediction that the combined highlighting-plus-regulation training would have more beneficial effects than the highlighting-only training. However, the combined training was not more effective than the control condition.

Did students in the strategy training groups report that they had applied the highlighting strategy? Did students in the highlighting-plus-regulation group show higher quality highlighting than students in the highlighting-only group?

As a manipulation check, students were asked to rate whether they had identified and paid attention to important information while studying the science text. An analysis of variance revealed significant differences between the three experimental groups, F(2,

43) = 12.22, $p < 0.001$, $MSE = 0.28$, $\eta^2 = 0.36$. Planned comparisons showed that both the highlighting-only and highlighting-plus-regulation groups reported more strategy use than the control group did, $t(43) = 4.33$, $p < 0.001$, $d = 1.51$, and $t(43) = 4.11$, $p < 0.001$, $d = 1.42$, respectively. These results indicate that students in the strategy training groups reported applying the highlighting strategy while studying the science text. The traces confirmed this pattern as both the highlighting-only and highlighting-plus-regulation groups had circled about five of the six main ideas and highlighted a considerable number of important concepts.

Concerning the quality of highlighting, analyses of covariance with type of training (highlighting-plus-regulation, highlighting-only) as a between-subjects factor, quality indicators (main ideas, important concepts, less important concepts) as dependent variables, and prior knowledge as a covariate yielded no significant group differences for the number of main ideas, $F(1, 26) < 1$, number of important concepts, $F(1, 26) = 1.15$, $p = 0.294$, and number of less important concepts, $F(1, 26) = 1.74$, $p = 0.199$. The effect of the covariate was not significant in any of the analyses (*F*s < 1). Contrary to our predictions, the quality of the highlighting did not differ significantly between the highlighting-only and highlighting-plus-regulation groups. For exploratory purposes, we took a closer look at the means. Although the highlighting-only group underlined about the same number of main ideas (5.3 vs. 5.0) and important concepts (26.9 vs. 23.5) as the highlighting-plus-regulation group did, the highlighting-plus-regulation group underlined about 51 fewer unimportant words than the highlighting-only group did ($d = 0.50$). In addition, there was high variability among the students ranging from 18 to 862 unimportant words that were underlined ($SD = 155.7$).

Discussion

Our results on declarative strategy knowledge about highlighting and the metacognitive regulation of highlighting were as expected: Both training groups acquired knowledge of the highlighting strategy, but only the highlighting-plus-regulation group acquired knowledge about how to monitor and control strategy use. Thus, students acquired specific strategy knowledge according to the specific training condition, indicating not only convergent but also discriminant effects of the training programs.

In terms of text comprehension, the highlighting-only group was outperformed by the control group. This was surprising given that the highlighting-only group gained strategy knowledge and evidently applied the highlighting strategy. However, Peterson (1992) also found a negative effect of highlighting on comprehension, and these results are consistent with our theoretical expectations about the lower potential for comprehension offered by the highlighting strategy. In line with our predictions, the highlighting-plus-regulation group outperformed the highlighting-only group. This finding indicates that the self-regulation training component served to compensate for the negative effect of the highlighting-only training and thus emphasizes the importance of being trained to use a strategy in a high-quality manner. The finding that the highlighting-plus-regulation group did not outperform the control group suggests that the compensatory effect is limited by the low comprehension potential of the highlighting strategy. When applying the highlighting strategy, students may focus on the text itself rather than on the contents described therein. Students may concentrate on merely *identifying* important concepts, thereby engaging in piecemeal processing (Garner 1981) and may fail to *combine* these concepts into a coherent structure.

In terms of strategy application, our analysis of self-reports showed that students in the strategy training groups reported paying more attention to important information than the students in the control group did. The analysis of the traces showed that the students in the training groups actually applied the strategies (i.e., they identified the main ideas and important concepts of the text); however, there was no significant difference between the highlighting-only group and the highlighting-plus-regulation group. On a descriptive level, the data suggest that the regulation component reduced the degree to which unimportant information was highlighted rather than improving the degree to which higher level information was highlighted.

Experiment 2: mapping strategy

In Experiment 2, we examined the effect of training in metacognitive self-regulation of a knowledge-mapping strategy on text comprehension. The mapping strategy was chosen because we considered it better able to facilitate the construction of a coherent representation of text information than the highlighting strategy. Knowledge or concept mapping is a learning strategy that supports the hierarchical organization and explicit representation of text information. A knowledge or concept map is a two-dimensional graphical display that represents key ideas as nodes, which are connected by labeled links (Dansereau et al. 1979; Mandl and Fischer 2000; O'Donnell et al. 2002). From the perspective of learning strategy approaches, knowledge mapping is a cognitive strategy that facilitates the organizational function of active information processing (Mayer 1996; Weinstein and Mayer 1986). Creating a knowledge map requires learners to identify important ideas and to look for interrelations among them—activities that characterize deep-level processing (Marton and Säljö 1997). A knowledge map is also regarded as a kind of propositional graphic that represents the gist of the information in an abstract propositional format (Kintsch 1998).

We expected that the mapping strategy would have the potential to improve comprehension more than the highlighting strategy because learners using mapping are required to convert linear textual statements into a nonlinear graphical representation and are thus less focused on the original wording of the text. However, when selecting and arranging text concepts and their explicit interrelations into nodes and labeled links, learners operate with symbolic representations, and there is no guarantee that they will retain the inherent structural features of the objects and elements that are described in the text. Consequently, the probability that the contents of the text will be processed only superficially is not necessarily reduced.

Empirical evidence concerning the effectiveness of the mapping strategy has been mixed such that students instructed or trained to construct knowledge maps or concept maps do not necessarily show enhanced text comprehension (Chang et al. 2002; Hardy and Stadelhofer 2006; Hilbert and Renkl 2008; Kiewra et al. 1989; McCagg and Dansereau 1991; Redford, Thiede, Wiley, & Griffin, 2012; Stull and Mayer 2007; but see Chmielewski and Dansereau 1998, and Dansereau et al. 1979, for positive effects of knowledge mapping). Explanations for these findings include the ideas that mapping is difficult to master and imposes too much mental load on the learner (Chang et al. 2002) and that the strategy may be too time-consuming to be useful (McCagg and Dansereau 1991). We suggest that the inconsistent findings may also be attributed to the fact that the mapping strategy focuses learners' attention on explicit text information as opposed to the referential contents and thus results in the strategy being applied in a low-quality way. For example, Hilbert and Renkl (2008) conducted an exploratory cluster analysis and identified unsuccessful and successful mappers by using variables that were specific to the mapping procedure and related to learning outcomes (e.g., number of labeled links, cognitive processes assessed by think-aloud protocols). The analysis revealed that unsuccessful mappers more frequently reported information about the map construction process per se without referring to the mapped contents. By contrast, successful mappers concentrated more on the contents presented by the map, included more labeled links, expressed more thoughts about the relations between concepts, and reflected more on their understanding while constructing the map. In addition, quality indicators of concept maps such as the number of correctly labeled links were significantly related to learning outcomes (Hilbert and Renkl 2008). Chularut and DeBacker (2004) found that a mapping training group provided with experimenter-generated feedback on the quality of their maps with regard to clarity and accuracy outperformed an individual study group. The feedback may have prompted students to process the contents described by their maps at a deeper level. In sum, these results suggest that activating students to reflect on and focus on the quality of their concept maps, whether provided or self-constructed, is central for deep understanding.

Experiment 2 was designed to test whether students could successfully be trained to construct their own knowledge maps and to regulate the quality of their maps when learning from a science text. A combination of mapping plus self-regulation training was compared with a mapping-only training and a control condition. Analogous to Experiment 1, the dependent variables were strategy knowledge, self-reported strategy application, map quality, and text comprehension.

Hypotheses about strategy knowledge

We predicted that the mapping-only and mapping-plus-regulation groups would not differ in their knowledge of the mapping strategy because both groups received the same mapping training. However, we expected that the mapping-plus-regulation group would outperform the mapping-only group on knowledge of self-regulation.

Hypotheses about strategy application

We assessed strategy application by analyzing students' self-reports about their organization of text information and the traces they produced while studying the science text (i.e., their maps). We expected both the mapping-only and the mapping-plus-regulation groups to report more cognitive strategy use than the control group because both groups were trained to organize the text information. We expected the mapping-plus-regulation group to produce qualitatively better maps than the mapping-only group because only students in the mapping-plus-regulation group were trained to self-regulate the quality of their maps.

Hypotheses about comprehension

We expected the mapping-plus-regulation group to outperform both the mapping-only group and the control group. However, given the weak empirical evidence from previous research, we did not formulate a prediction about whether the mapping-only group would outperform the control group.

Method

Participants and design

The participants were 62 Grade-10 students from two secondary high schools. The study employed a between-subjects design with type of strategy training (mapping plus regulation, mapping only, and control) as a single factor. Prior knowledge of text contents was used as a covariate to assess knowledge acquired in the learning phase. Within each school, students were randomly assigned to one of the three experimental groups. The mapping-plus-regulation group comprised 21 students, the mapping-only group 19 students, and the control group 21 students. One student had to be excluded from the analyses because this student did not complete the materials appropriately. Their mean age was 15.48 years (SD = 0.62), and the percentage of female students was 47.6 %

Materials

The learning and testing materials were identical to those used in Experiment 1 except that students were trained to use the mapping strategy.

The training program

The structure of the training program was identical to that used in Experiment 1. First, a mapping example (Daniel) introduced students to the steps of the mapping strategy. The mapping-plus-regulation version also included a self-regulation example. Second, a training component gradually elaborated the steps of the strategy and had students practice them. The mapping-plus-regulation version included a self-regulation strategy section elaborating on the steps of the self-regulation process and providing corresponding exercises.

The mapping example was again based on a fictitious student, Daniel, who is preparing for a biology test and realizes that he does not understand the learning materials. He decides to apply a mapping strategy to help clarify the relations between scientific concepts. He works through the first chapter of his course book by applying the following steps: (1) read a paragraph and highlight important concepts, (2) write down the concepts and arrange them spatially, (3) draw links between related concepts, (4) label the links between the concepts. These steps are based on the networking strategy developed by Dansereau and colleagues (Chmielewski and Dansereau 1998; Holley and Dansereau 1984; McCagg and Dansereau 1991). In the mapping-plus-regulation version, the self-regulation example is then presented. Daniel reflects on his strategic processing. He self-observes how accurately he has applied the mapping strategy. He self-assesses whether he has succeeded in clarifying the relations between important concepts. He reacts to this self-assessment by adjusting his strategy processing accordingly.

In the mapping strategy section, the individual steps of the strategy are gradually elaborated and enriched with additional information and exercises. Learners are first informed about the goal of the mapping strategy: to help them identify and clarify important relations between text concepts. Holley and Dansereau (1984) distinguished six kinds of links specifying relations between concepts. Four are implemented in the training program: type-part links (hierarchy), type-of links (hierarchy), leads-to links (causal chains), and characteristic-of links (cluster). Learners are presented with examples of each link type and told that they represent basic conceptual relations and can be completed by self-generating more links. The steps of the mapping strategy are then presented and explained with corresponding practice items to revise and to consolidate the students' declarative knowledge about the strategy. As the training program also conveys procedural knowledge, the trainer first models the application of the mapping strategy using a typical passage from a biology textbook. The text passages used in the training pertained to human blood and its components. Students are then asked to apply the strategy step by step using the biology passages that are provided. The trainer monitors students' progress and provides feedback on each step. Students gradually learn to apply the strategy on their own through scaffolding and the fading out of the trainer. Finally, students are informed about when and why to use the mapping strategy—that is, they are given conditional knowledge of strategy use.

In the self-regulation component, the steps of the self-regulation strategy are presented, explained, and practiced following the same sequence as in Experiment 1. Students are trained to self-observe and self-assess the accuracy of their application of the mapping strategy and to react appropriately. For example, students who realize that their map does not help them to clarify relations between important concepts are encouraged to re-read relevant text passages and to revise their map accordingly.

Control group

Students in the control group read and presented English texts. The learning materials were identical to those from Experiment 1.

Learning and testing materials

The materials were identical to those used in Experiment 1 with the exceptions that the strategy knowledge test assessed knowledge of the mapping strategy and self-regulation strategy and that the self-report strategy questionnaire assessed use of the mapping strategy during text processing. The internal consistency of the multiple-choice comprehension test was Cronbach's $\alpha = 0.82$.

The strategy-knowledge test consisted of 12 single-choice questions, with six items measuring knowledge of the mapping strategy (e.g., "What kind of relation is labeled with a "type-part" link? (a) A causes B, (b) A is a characteristic of B, (c) A consists of B") and six items for measuring knowledge of the self-regulation strategy (e.g., "How should you react if you do not understand the relations described in a text? (a) memorize your map, (b) revise your map, (c) set a new learning goal").

A self-report scale was developed to assess whether students reported applying the mapping strategy with a focus on organizational processes. Students were asked to rate on a 4-point scale (ranging from completely agreeing to completely disagreeing) whether they had organized the text contents (sample items: "I searched for logical relations between the concepts in the text," "I created a structure in which I connected important concepts to each other," "I considered explanations of the issues described in the text"; five items, Cronbach's $\alpha = 0.60$).

Procedure

The procedure was identical to that used in Experiment 1 with the exception that the students were given 35 min to study the science text on water molecules because we expected map construction to take longer than highlighting. The experimental groups were instructed to apply the mapping strategy. The mapping-plus-regulation group was additionally instructed to apply the self-regulation strategy. The control group was told to read the text for comprehension. All students were aware that comprehension of the text would be tested.

Analysis of maps

We assessed the quality of strategy use by analyzing the knowledge maps produced by the students. Research on concept mapping and knowledge mapping has identified a variety of scoring techniques (for an overview, see Nicoll et al. 2001), most of which emphasize the importance of noted ideas (concepts) and the links between them. Links are considered more important than ideas and have been shown to be better predictors of comprehension scores (Hilbert and Renkl 2008; Nicoll et al. 2001; Ruiz-Primo and Shavelson 1996; Slotte and Lonka 1999; Stensvold and Wilson 1990). We therefore scored the main ideas and links included in the students' maps. Comparable to Experiment 1, we further distinguished between irrelevant ideas and irrelevant links because we expected the numbers of both relevant and irrelevant ideas and links to be crucial aspects of the quality of the maps: An accurate and well-structured map includes many relevant ideas and relations but fewer irrelevant ideas and relations. We analyzed students' maps with reference to instructor-generated expert maps, a conventional method for analyzing student-generated maps (Rye and Rubba 2002). Expert maps were independently constructed by a science teacher and the first author. Differences were discussed and resolved to produce expert maps for each text paragraph. The expert maps included (similar to Experiment 1) 47 important concepts plus six main ideas, resulting in a maximum number of 53 relevant ideas. The maximum number of relevant links was 41.

The student maps were then analyzed with reference to the expert maps. First, the overall number of nodes (ideas) and links in each student map were counted. Then the number of relevant ideas (those conforming to the expert map) were counted. The number of irrelevant ideas was calculated by subtracting the number of relevant ideas from the overall number of ideas. Two raters assessed whether each relation of the expert concept maps was found in the student maps. Interrater agreement was $\kappa = 0.97$. The number of irrelevant links was calculated by subtracting the number of relevant links from the overall number of links.

Results

Before testing the hypotheses, we examined whether the three treatment groups differed in their verbal ability and prior knowledge scores (see Table 2 for means and standard deviations). No between-group differences were found for verbal ability $F(2, 58) < 1$, or for prior knowledge, $F(2, 58) = 1.23$, $p = 0.300$.

Table 2

Means (standard deviations) of dependent variables in the mapping experiment

	Experimental condition		
	Control	Mapping only	Mapping plus self-regulation
Knowledge			
About mapping		5.05 (0.97)	4.67 (0.91)
About self-regulation		3.95 (1.18)	5.00 (0.77)
Comprehension test	45.60[a] (5.02)	44.94[a] (6.43)	49.64[a] (4.42)
	46.67[b] (8.08)	45.05[b] (7.22)	48.48[b] (5.59)
Strategy use	2.52 (0.57)	3.25 (0.46)	2.92 (0.54)
Quality indicators			
Relevant ideas		22.84[a] (9.81)	21.33[a] (11.35)
		22.63 [b] (9.71)	21.52[b] (11.61)
Irrelevant ideas		50.63[a] (26.41)	49.62[a] (51.21)
		49.05[b] (26.61)	51.05[b] (52.99)
Relevant links		9.71[a] (5.85)	9.78[a] (6.93)
		9.68 [b] (5.82)	9.81[b] (6.95)
Irrelevant links		7.61[a] (4.45)	4.67[a] (2.99)
		7.58 [b] (4.46)	4.71[b] (3.02)
Prior knowledge	27.76 (4.46)	26.95 (3.49)	25.86 (3.77)

	Experimental condition		
	Control	Mapping only	Mapping plus self-regulation
Verbal ability	16.29 (4.31)	15.16 (4.48)	16.76 (3.60)

Note. MSE = 28.63

[a]Adjusted for prior knowledge

[b]Unadjusted scores

Did students in the training groups acquire knowledge of the strategies they were trained to use?

The results of the strategy knowledge test showed that both training groups acquired knowledge about the mapping strategy (their test performance was far above the probability of guessing) but did not differ significantly in the level of mapping knowledge acquired, $t(38) = 1.30$, $p = 0.203$. However, the mapping-plus-regulation group acquired more knowledge of how to monitor and control their strategy use than the mapping-only group did, $t(38) = 3.37$, $p = 0.002$, $d = 1.08$ (see Table 2 for means and standard deviations).

Did students in the mapping-plus-regulation group understand the text contents better than students in the mapping-only group and control group?

To examine overall differences in comprehension test scores across experimental groups, we calculated an ANCOVA with treatment as the between-groups factor and prior knowledge as a covariate. Before computing the analysis, we tested for the homogeneity of the regression: The regression slopes for predicting comprehension performance by prior knowledge did not vary across the treatment groups, $F(2, 55) = 1.14$, $p = 0.328$. The ANCOVA revealed a statistically significant effect of prior knowledge, $F(1, 57) = 38.38$, $p < 0.001$, $MSE = 28.63$, $\eta^2 = 0.40$, and an overall effect of the treatment, $F(2, 57) = 4.50$, $p = 0.015$, $MSE = 28.63$, $\eta^2 = 0.14$. Planned comparisons on the adjusted means (Jaccard 1998) showed that, as expected, the mapping-plus-regulation group outscored the mapping-only group, $t(57) = 2.77$, $p = 0.007$, 95 % CI [1.38, 8.02], $d = 0.88$, and the mapping-plus-regulation group outscored the control group, $t(57) = 2.45$, $p = 0.018$, 95 % CI [0.80, 7.28], $d = 0.76$. The mapping-only group and the control group did not differ from each other, $t(57) < 1$, 95 % CI [−2.65, 3.97], $d = -0.12$ (see Table 2). These results indicate that students who received combined mapping-plus-regulation training understood the text better than students who received mapping-only training or students in the control group, whereas the mapping-only group and the control group did not differ from each other.

Did students in the training groups report that they had applied the mapping strategy? Did students in the mapping-plus-regulation group produce higher quality maps than students in the mapping-only group?

To assess whether students applied the strategies that they were trained to use, we analyzed their self-reports and traces. As a manipulation check, students were asked to rate whether they had mentally organized the text information while studying the science text. These cognitive processes are assumed to underlie the mapping strategy. An analysis of variance revealed significant differences between the experimental groups, $F(2, 58) = 9.69$, $p < 0.001$, $MSE = 0.28$, $\eta^2 = 0.25$. Planned comparisons confirmed that both the mapping-only and mapping-plus-regulation groups reported more organization of text information than the control group did, $t(58) = 4.39$, $p < 0.001$, $d = 1.42$, and $t(58) = 2.43$, $p = 0.018$, $d = 0.72$, respectively. These results show that trained students reported applying the mapping strategy while studying the text.

In order to assess the quality of the students' maps, we conducted univariate analyses of covariance with type of experimental treatment (mapping-only, mapping-plus-regulation) as the factor and the quality indicators as dependent variables. Prior knowledge was used as a covariate. The analyses yielded no significant group differences with respect to the number of relevant ideas, irrelevant ideas, and relevant links noted, all $F < 1$. However, the mapping-plus-regulation group noted significantly *fewer* irrelevant links than the mapping-only group, $F(1, 37) = 6.07$, $p = 0.018$, $d = 0.79$ (see Table 2 for means, adjusted means, and standard deviations). The effect of the covariate was not significant in any of the analyses (*p*s > 0.147), and there was no interaction between prior knowledge and the treatment (*p*s > 0.304). In sum, this result indicates that the mapping-plus-regulation training can enhance map quality by reducing the number of irrelevant links between the main ideas.

Discussion

Our results on declarative strategy knowledge about mapping and the metacognitive regulation of mapping were as expected: Both training groups acquired knowledge of the mapping strategy, but the mapping-plus-regulation group gained more knowledge of how to monitor and control strategy use than the mapping-only group did. Thus, students acquired specific strategy knowledge according to the experimental treatment.

In terms of text comprehension, evidence from this and other studies (Chang et al. 2002; Hardy and Stadelhofer 2006; Redford et al., 2012; Stull and Mayer 2007) showed that producing self-constructed maps in the mapping-only condition had no benefits relative to reading alone in the control condition. However, in contrast to the highlighting strategy (Experiment 1), the mapping strategy did not prove to be counterproductive, perhaps because students focused more on establishing links between important ideas when creating the knowledge map. When specifying fairly concrete links, such as "type-part" or "characteristic-of" links, students may even have devoted resources to mental model building. The mapping-plus-regulation group outperformed both the mapping-only group and the control group. These results demonstrate the specific value of training a strategy in conjunction with its metacognitive regulation.

With regard to strategy application, self-reports showed that both treatment groups reported mentally organizing the learning materials—a process that is explicitly supported by the mapping strategy. The training groups reported concentrating on conceptual relations more than the control group did. In terms of the quality of their maps, the mapping-plus-regulation group included fewer irrelevant links in their maps than the mapping-only group did. These results and the effects on comprehension performance suggest that the mapping-plus-regulation group engaged in more reflective processing when creating their maps, which may have prompted them to reduce the number of irrelevant links.

Experiment 3: visualizing strategy

In Experiment 3, we tested the effectiveness of a visualizing strategy that was expected to focus learners' attention more on "what the text is about" than on the text itself. The visualizing strategy trained in this study, also known as the drawing-construction strategy (Van Meter 2001), fosters the construction of external pictorial representations of the text contents that are to be learned (Gilbert 2008). For example, a student reading about water molecules might draw a sketch of a water molecule and its chemical bonds in order to depict the structural relations between the text concepts. Gilbert (2008) points out that such types of visualizations play a prominent role in how science education is conducted.

According to learning strategy approaches, this visualizing strategy facilitates the organization and integration functions of active information processing (Weinstein and Mayer 1986). When visualizing, the learner has to visually represent and spatially organize the elements involved, thereby creating a holistic representation of the elements and their interrelations. The visualizing strategy supports mental model building more directly because learners are required to use representations that are related to their referents through structural or functional similarity (Leopold and Leutner 2012). When visualizing, students transform verbally presented information into pictorial information, thus concentrating on "what the text is about" rather than on the text itself (i.e., the original wording). These cognitive processes characterize deep-level processing because learners focus on "what is signified"—the situation described in a text or the intentional content of the text (Marton and Säljö 1976). The comprehension potential of the visualizing strategy is thus expected to be high, and surface processing seems less likely (for a review of visualizing strategies, see De Koning and Schoot 2013).

Research on the drawing-construction strategy has indicated that the quality of visualizations is crucial for understanding (see the review by Van Meter and Garner 2005). Several studies have reported that drawing accuracy was strongly related to learning performance in elementary school students (r = 0.57; Lesgold et al. 1975a) and in high school students (r = 0.50; Leopold et al. 2013). In Grade-5 and Grade-6 students, Van Meter (2001) compared learning from texts with drawing instructions and learning from texts with experimenter-provided pictures. They found that students did not benefit from drawing instructions alone. However, when instructional support was provided, not only did the quality of the drawings improve, but learning performance did too. In older or college-aged readers, a number of studies have found positive effects of drawing instructions (Alesandrini 1981; Hall et al. 1997; Leopold and Leutner 2012), whereas others have not (Kulhavy et al. 1985; Leutner et al. 2009).

Given that many students seem to encounter problems when visualizing text contents, fostering the accuracy and hence the quality of drawings should improve text comprehension. For example, in the Hall et al. (1997) study in which drawing was beneficial, students were given very specific instructions on how to accurately sketch the operation of a bicycle tire pump. In another study in which drawing turned out to be beneficial as well, Schwamborn et al. (2010) and Schwamborn et al. (2011) used drawing prompts, that is, a toolbar showing pictorial elements that could be used for drawing and a partially predrawn background. These and van Meter's (2001) results indicate that students can benefit from the strategy when specific instructions on "how to construct a drawing" are provided. To our knowledge, no comprehensive conceptions for training the visualizing of text contents have yet been developed. Lesgold et al. (1975b), for example, included drawing instructions as a training component in their study on how mental imagery can foster the recall of text information, but these played only a minor role.

Experiment 3 was designed to test whether students could successfully be trained to construct their own visualizations of the information presented in a text and to regulate the quality of their visualizations. A combination of visualizing and self-regulation training was compared with a visualizing-only training and a control condition. Analogous to Experiments 1 and 2, the dependent variables were strategy knowledge, self-reported strategy application, drawing quality, and text comprehension.

Hypotheses about strategy knowledge

We predicted that the visualizing-only and the visualizing-plus-regulation groups would not differ in their knowledge of visualizing. However, we expected the visualizing-plus-regulation group to outperform the visualizing-only group on knowledge of self-regulation.

Hypotheses about strategy application

We assessed strategy application by analyzing students' self-reports of the degree to which they could form mental images of the text contents and the traces they produced while studying the science text (i.e., their drawings). We expected both the visualizing-only and the visualizing-plus-regulation groups to report more mental imagery than the control group because the two treatment groups were trained to perform visualizations, and mental imagery is assumed to underlie the construction of external visualizations. We expected the visualizing-plus-regulation group to produce qualitatively better drawings than the visualizing-only group because only students in the visualizing-plus-regulation group were trained to self-regulate the quality of their visualizations.

Hypotheses about comprehension

We expected the visualizing-plus-regulation group to outperform both the visualizing-only group and the control group. Given the hypothesized high comprehension potential of the visualizing strategy, we expected the visualizing-only group to outperform the control group as well.

Method

Participants and design

Participants were 49 Grade-10 students from a secondary high school. The study employed a between-subjects design with type of strategy training (visualizing-plus-regulation, visualizing only, and control) as a single factor. Prior knowledge of text contents was used as a covariate to assess knowledge acquired during the learning phase. Within their classes, students were randomly assigned to one of the three experimental groups. The visualizing-plus-regulation group comprised 15 students, the visualizing-only group 17 students, and the control group 17 students. Their mean age was 15.96 years (*SD* = 0.46), and the percentage of female students was 55.1 %.

Materials

The learning and testing materials were identical to those used in Experiments 1 and 2 except that the participants were trained to use the visualizing strategy.

The training program

The structure of the training program was identical to that used in Experiments 1 and 2. First, a visualizing example (Daniel) was presented, with an additional self-regulation example in the visualizing-plus-regulation version. Second, a training component on visualizing followed, with an additional self-regulation strategy component in the visualizing-plus-regulation version.

The visualizing example was again based on a fictitious student, Daniel, who is preparing for a biology test and realizes that he does not understand the learning materials. He decides to apply a visualizing strategy to improve his comprehension. He works through the first chapter of his course book applying the following steps: (1) read a paragraph, (2) construct a drawing of the text contents, (3) imagine the drawing, and (4) figure out how the drawing is related to the information from the preceding paragraphs. Students learned to pay attention to words denoting spatial relations between objects and to translate them into a pictorial representation. The conception of the strategy steps was based on research on the drawing-construction strategy (Hall et al. 1997; van Meter 2001), mental model construction (Ehrlich and Johnson-Laird 1982; Johnson-Laird 1983), and mental imagery (Denis and Cocude

1989; Kosslyn et al. 1988). In the visualizing-plus-regulation version, Daniel reflects on his strategic processing. He self-observes how he has applied the visualizing strategy. He self-assesses whether his drawings have correctly represented the text contents. He reacts to this self-assessment by adjusting his strategic processing accordingly.

In the visualizing strategy component, the individual steps of the strategy are gradually elaborated and enriched with additional information and exercises. Learners are informed about the goal of the visualizing strategy: to help them clarify the structure and relations of the contents that are to be learned. The individual steps of the strategy are then presented, explained, and practiced to revise and consolidate declarative strategy knowledge. Procedural knowledge is trained as well. First, the trainer models the application of the visualizing strategy based on a typical passage from a biology textbook. The text passages used in the training pertained to the functioning of the human blood circulatory system. Students are then asked to apply the strategy step by step as the trainer monitors their progress. Students gradually learn to apply the strategy on their own through scaffolding and the fading out of the trainer. Finally, students are informed about when and why to use the visualizing strategy—that is, they are given conditional knowledge of strategy use. Similar to the focus of the mapping strategy, the main focus of this visualizing strategy is on organizing information and on clarifying relations between the elements. However, the student is not asked to operate with words but rather to organize elements and objects in a visual-spatial format.

In the self-regulation component, the steps of the self-regulation strategy are presented, explained, and practiced following the same sequence as in Experiments 1 and 2. Students are trained to self-observe and self-assess whether they have accurately applied the visualizing strategy and to react appropriately in order to improve the accuracy and clarity of their drawings.

Control group

Students in the control group read and presented English texts. The learning materials and instructions were identical to those described in Experiment 1.

Learning and testing materials

The materials were identical to those used in Experiments 1 and 2 with the exceptions that the strategy knowledge test assessed knowledge of the visualizing strategy and self-regulation strategy, the self-report strategy questionnaire assessed use of mental imagery during text processing, and a measure of spatial ability was included. Two items were added to the multiple-choice comprehension test resulting in 18 items (maximum score of 72). The internal consistency of the multiple-choice comprehension test was Cronbach's $\alpha = 0.71$.

The strategy knowledge test consisted of 14 single-choice questions, with seven items measuring knowledge of the visualizing strategy (e.g., "What advantages are attributed to mental models? (a) they represent all characteristics of an object, (b) they can be mentally modified and changed, (c) they represent pictures and words") and seven items measuring knowledge of the self-regulation strategy (e.g., "In the 'reacting' step, you consider… (a) which steps you applied to construct the mental model, (b) whether you need to apply the visualizing strategy any further, (c) whether you understood the text contents").

A self-report scale was used to assess whether students reported forming mental images of the text contents. Students were asked to rate on a 4-point scale (ranging from completely agreeing to completely disagreeing) whether they imagined the text contents (sample item: "I imagined the contents described in the text"; five items, Cronbach's $\alpha = 0.87$).

In addition to verbal ability, spatial ability was measured using the paper-folding test (Ekstrom et al. 1976) because Denis (2008) found that the quality of student-generated images of a verbal description varied as a function of students' spatial abilities. High visuo-spatial imagers could better assess the distances between their image components than low visuo-spatial imagers.

Procedure

The procedure was identical to that used in Experiments 1 and 2 with the exception that the spatial ability test (3 min) was administered after the verbal ability test. In the strategy application phase of the experiment, students were given 35 min to study the text on water molecules. The experimental groups were instructed to apply the visualizing strategy. The visualizing-plus-regulation group was additionally instructed to apply the self-regulation strategy. The control group was told to read the text for comprehension. All students were aware that they would be tested on their comprehension of the text.

Analysis of student drawings

We assessed the quality of strategy use by analyzing the drawings produced by the students. There are only a few procedures for scoring self-constructed drawings (Hall et al. 1997; Leopold and Leutner 2012; Lesgold et al. 1975a; Schwamborn et al. 2010; Van Meter 2001). As most of these procedures involve general measures of drawing accuracy, we developed three quality indicators for our drawings that were analogous to the indicators used in Experiments 1 and 2: (a) the overall number of relevant text concepts visualized (independent of their accuracy), (b) the accuracy of these visualizations, and (c) the number of text concepts loaded with irrelevant details. As in Experiment 2, students' drawings were analyzed with reference to instructor-generated expert drawings. Expert drawings were independently constructed by a science teacher and the first author. Differences were discussed and resolved to produce 10 reference drawings representing the important concepts and processes described in the text. The number of reference drawings was based on these six topics but exceeded the number of paragraphs because some paragraphs covered more than one important concept. For example, in some cases, one topic could not be depicted in a single drawing because information was contrasted or involved different parts of the same process (e.g., a first drawing was needed to illustrate ionic bonding between sodium and chlorine ions within a salt crystal before the process of hydration, and a second drawing of a hydration shell was needed to depict single sodium and chlorine ions surrounded by water molecules after the process of hydration). Pedagogical content knowledge on the learning of chemical subject matter was taken into account in constructing these drawings.

In the first step of the analysis, two raters (the science teacher and first author) assessed how many of 10 concepts and processes were visualized by the students, irrespective of the accuracy of the drawings (0 or 1 point per visualization; interrater agreement of $\kappa = 0.99$). In a second step, the accuracy of the drawings was scored. To this end, a checklist was developed for each of the 10 reference drawings specifying the characteristics that had to be fulfilled for a drawing to be scored as accurate (2 points), partly accurate (1 point), or inaccurate (0 points). These characteristics referred to the inclusion of relevant components (objects or structures) and the extent to which these components were accurately arranged in relation to each other in space (Leopold and Leutner 2012). Two raters coded the student-generated drawings with reference to the expert drawings and the experimenter-generated checklists (0/1/2 points). Interrater agreement was $\kappa = 0.88$. In a third step, the two raters evaluated whether each of the drawings identified in Step 1 included irrelevant details (0 or 1 point per drawing; $\kappa = 0.97$) such as redundant elements that did not support the understanding of the concepts and processes depicted.

Results

Before testing the hypotheses, we examined whether the three treatment groups differed in their verbal ability, spatial ability, and prior knowledge scores. No between-group differences were found for verbal ability, $F(2, 46) = 1.16$, $p = 0.323$, $MSE = 10.14$, or spatial ability, $F(2, 46) < 1$, $MSE = 9.63$ (see Table 3 for means and standard deviations). There was a difference in students' prior knowledge scores, $F(2, 46) = 6.37$, $p = 0.004$. A post hoc test showed that the visualizing-only group scored higher than the visualizing-plus-regulation group ($p = 0.003$). All other differences were not significant. Prior knowledge was included as a covariate in the analyses of the trace data and learning performance.

Table 3

Means (standard deviations) of dependent variables in the visualizing experiment

	Experimental condition		
	Control	Visualizing only	Visualizing plus self-regulation
Knowledge			
About visualizing		4.94 (1.25)	5.20 (1.01)
About self-regulation		1.53 (0.94)	4.27 (1.10)
Comprehension test	46.27[a] (5.91)	50.72[a] (5.96)	51.08[a] (6.56)
	46.18[b] (5.66)	51.41[b] (6.00)	50.40[b] (7.05)
Strategy use	2.46 (0.89)	3.05 (0.83)	3.18 (0.60)
Quality indicators			
Relevant visualized concepts		5.99[a] (2.30)	7.80[a] (2.23)
		6.18[b] (2.40)	7.60[b] (2.32)
Accuracy of visualized concepts		7.51[a] (4.25)	11.87[a] (3.97)
		8.00[b] (4.53)	11.33[b] (4.44)
Irrelevant details in visualized concepts		1.24[a] (1.36)	0.41[a] (0.73)
		1.12[b] (1.45)	0.53[b] (0.74)
Prior knowledge	24.88 (2.47)	26.94 (3.31)	23.33 (2.77)
Verbal ability	14.71 (2.34)	16.35 (3.08)	15.73 (4.03)

	Experimental condition		
	Control	Visualizing only	Visualizing plus self-regulation
Spatial ability	5.12 (3.14)	3.94 (3.25)	5.20 (2.88)

Note. MSE = 38.42

[a]Adjusted for prior knowledge

[b]Unadjusted scores

Did students in the training groups acquire knowledge of the strategies they were trained to use?

Results of the strategy knowledge test showed that both training groups acquired knowledge of the visualizing strategy (their test performance was far above the probability of guessing) but did not differ significantly in their level of visualizing knowledge acquired, $t(30) < 1$. However, the visualizing-plus-regulation group acquired more knowledge about how to monitor and control strategy use than did the visualizing-only group, $t(30) = 7.58$, $p < 0.001$, $d = 2.69$ (see Table 3 for means and standard deviations).

Did students in the visualizing-plus-regulation group understand the text contents better than students in the visualizing-only and control groups, and did students in the visualizing-only group outperform the control group?

To examine overall differences in science comprehension test scores across experimental groups, we calculated an ANCOVA with treatment as the between-groups factor and prior knowledge as a covariate. Before computing the analyses, we tested for the homogeneity of the regression: The regression slopes for predicting comprehension performance by prior knowledge did not vary significantly across the treatment groups, $F(2, 43) = 2.03$, $p = 0.143$. The results of the ANCOVA showed no statistically significant effects of prior knowledge, $F(1, 45) = 2.00$, $p = 0.164$, $MSE = 38.42$, $\eta^2 = 0.04$, but did show a marginally significant overall effect of the treatment, $F(2, 45) = 3.10$, $p = 0.055$, $MSE = 38.42$, $\eta^2 = 0.12$. Planned comparisons on the adjusted means confirmed that both the visualizing-only group and the visualizing-plus-regulation group outscored the control group, $t(45) = 2.56$, $p = 0.014$, 95 % CI [1.51, 10.11], $d = 0.72$, and $t(45) = 2.20$, $p = 0.034$, 95 % CI [1.28, 9.62], $d = 0.78$, respectively. However, the visualizing-plus-regulation group and the visualizing-only group did not differ from each other, $t(45) < 1$, 95 % CI [−3.94, 4.66], $d = 0.06$.

In sum, there is evidence that both treatment groups benefitted from the visualizing training relative to the control condition. In contrast to the results of Experiments 1 and 2, the combined visualizing-plus-regulation training did not yield additional benefits.

Did students in the training groups report that they had applied the visualizing strategy? Did students in the visualizing-plus-regulation group produce higher quality visualizations than students in the visualizing-only group?

To assess whether students applied the strategies they were trained to use, we analyzed their self-reports and traces. As a manipulation check, students were asked to rate whether they formed mental images of the text information while studying the science text. The cognitive process of forming mental images is assumed to underlie the visualizing strategy. An analysis of variance revealed significant differences between the experimental groups, $F(2, 46) = 3.87$, $p = 0.028$, $MSE = 0.62$, $\eta^2 = 0.14$. Planned comparisons showed that, as expected, both the visualizing-only and the visualizing-plus-regulation group reported more mental imagery than the control group did, $t(46) = 2.17$, $p = 0.035$, $d = 0.69$, and $t(46) = 2.57$, $p = 0.014$, $d = 0.97$, respectively. Thus these results show that trained students reported applying the visualizing strategy while they studied the science text.

In order to assess the quality of students' drawings, we conducted univariate analyses of covariance with type of experimental treatment (visualizing-plus-regulation, visualizing-only) as factors and the quality indicators as dependent variables. Prior knowledge was included as a covariate. The analyses confirmed that students in the visualizing-plus-regulation condition visualized more relevant concepts, $F(1, 29) = 7.18$, $p = 0.012$, $d = 0.80$, constructed more accurate drawings, $F(1, 29) = 13.21$, $p = 0.001$, $d = 1.06$, and included fewer irrelevant details, $F(1, 29) = 6.13$, $p = 0.019$, $d = 0.79$, than the students in the visualizing-only condition did (see Table 3 for means and standard deviations). The effect of prior knowledge as a covariate was not significant in any of the analyses (ps > 0.170), and prior knowledge did not interact with the treatment (ps > 0.189).

To investigate the relation between drawing accuracy (accuracy of visualized relevant concepts) and performance on the comprehension test, we computed a correlation between the two measures. Like Lesgold et al. (1975a, b), Hall et al. (1997), and Schwamborn et al. (2010), we found that drawing accuracy was significantly positively related to text comprehension ($r = 0.37$, $p = 0.039$).

In sum, the visualizing-plus-regulation group outperformed the visualizing-only group on all three quality indicators.

Discussion

Our results on declarative strategy knowledge about visualizing and the metacognitive regulation of visualizing were as expected: Both treatment groups acquired knowledge of the visualizing strategy, but the visualizing-plus-regulation group gained more knowledge about how to monitor and control strategy use than the visualizing-only group did. Thus, students acquired specific strategy knowledge according to the experimental treatment.

In terms of text comprehension, the results demonstrate that explicit training in visualizing text contents positively affects comprehension—in contrast to visualizing instructions, which have sometimes been shown to be ineffective (Kulhavy et al. 1985; Lesgold et al. 1975a, b; Leutner et al. 2009). This benefit may be attributable to the specific guidance and assistance given to learners in how to construct external representations of text contents, a practice that fosters procedural strategy knowledge (see also Hall et al. 1997). In contrast to our predictions, however, a combined visualizing-plus-regulation training did not have a more beneficial effect than a visualizing-only training even though students in the visualizing-plus-regulation training condition produced more accurate drawings than the students in the visualizing-only training condition did.

In terms of strategy application, results indicated that both treatment groups reported applying the visualizing strategy and constructed mental images of the concepts described in the text. The training groups reported more mental imagery than the control group did. Simple comparisons revealed that visualizing-plus-regulation students constructed more accurate drawings than the visualizing-only students did in terms of the three indicators examined. In line with Van Meter's (2001) findings, our results suggest that learners can be trained to revise and thus to improve their drawings. Whereas in Van Meter's study, students were prompted by the experimenter to evaluate their drawings, our results show that students can also be trained to self-evaluate and self-adjust their drawings.

It might be concluded from these results that drawing accuracy did not facilitate comprehension as there was no difference between the visualizing only and the visualizing-plus-regulation groups in comprehension performance, but the positive correlation between drawing accuracy and text comprehension ($r = 0.37$) is not compatible with this interpretation. An alternative explanation can be derived by considering internal as well as external revision processes. Students may construct and revise their mental images without investing effort in constructing and revising their drawings; indeed, the former is assumed to require less mental effort than the latter (Leutner et al. 2009). Students in the visualizing-plus-regulation group were explicitly trained to revise their drawings, whereas students in the visualizing-only group were not. Given that both mental images and external drawings preserve the structural features of the contents described in a text, they may both provide learners with feedback on the accuracy of their representation. For example, a student wishing to mentally put an element in a place already occupied by another element will receive the feedback that this is not possible. Students thus have to adjust their visualization processes in relation to the features already displayed in their images or drawings. Thus, visualizing may be attributed an inherent metacognitive function, meaning that explicit training in metacognitive self-regulation has no notable additional benefits for comprehension. This interpretation is supported by the results of Van Meter (2001) who found that drawing instructions activated metacognitive processes for monitoring comprehension.

General discussion

The goal of the present set of experiments was to investigate whether text comprehension could be improved by improving the quality of learning strategies through metacognitive self-regulation. Three learning strategies (highlighting, mapping, visualizing) were compared to test whether training in metacognitive self-regulation would foster the application of strategies that each had a different potential to affect comprehension, that is, strategies that differed in the extent to which they could direct learner attention toward the text itself (i.e., explicit text information) or toward the contents described in the text (i.e., "what the text is about"). We expected learner attention to be more focused on the text itself during highlighting than mapping, or to an even greater extent, during visualizing.

Our findings for the strategy-only conditions were in line with these theoretical predictions as illustrated in Fig. 4 ("strategy effect"). Highlighting training proved to be counterproductive relative to the control condition ($d = -1.25$) as previously shown by Peterson (1992). Mapping training did not have statistically significant positive or negative effects ($d = -0.12$), congruent with findings by Chang et al. (2002), Hilbert and Renkl (2008), Stull and Mayer (2007), and Redford et al. (2012). Visualization training proved to be beneficial ($d = 0.72$) as previously reported by Hall et al. (1997) and Alesandrini (1981) for drawing instructions.

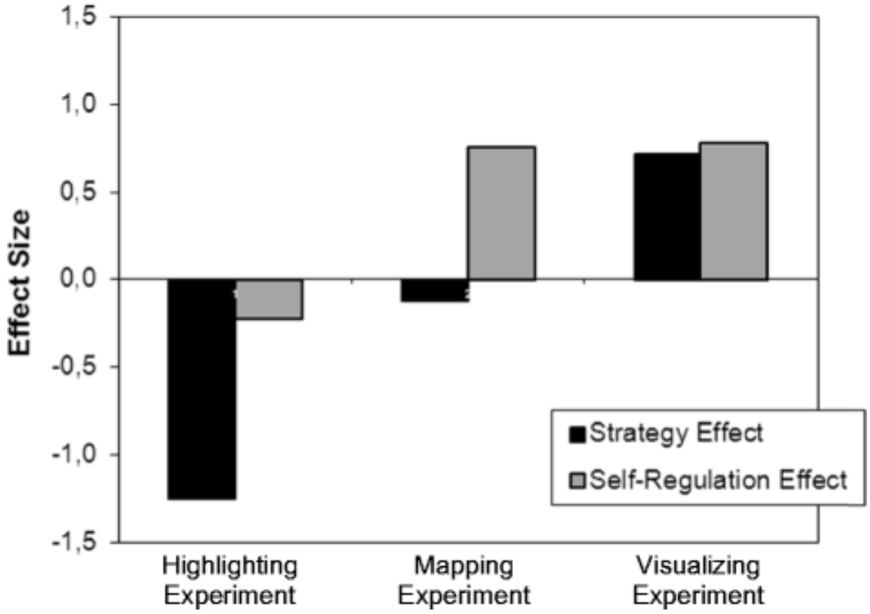

Fig. 4

Effect sizes for the strategy effect (strategy-only condition compared with control condition) and the self-regulation effect (strategy plus self-regulation conditions compared with control condition) on text comprehension. Note that the 0 line indicates the control-group baseline

A different pattern of results was obtained for a combined cognitive and metacognitive training of strategy use in comparison with the control condition as depicted in Fig. 4 ("self-regulation effect"): Highlighting-plus-regulation training did not differ from the control condition (*d* = −0.22), mapping-plus-regulation training was beneficial (*d* = 0.76), and so was visualizing-plus-regulation training (*d* = 0.78). These findings suggest that the metacognitive component of the training program may have helped the students overcome any limitations in their comprehension due to the cognitive strategy they were trained to apply (except when the cognitive strategy was effective by itself). Thus, whereas students in the highlighting-only group were outperformed by the control group, students in the highlighting-plus-regulation group performed as well as the control group. Students in the mapping-only group did as well as the control group, whereas students in the mapping-plus-regulation group outperformed the control group. Students in the visualizing-only group outperformed the control group as did students in the visualizing-plus-regulation group.

These findings indicate tight relations between cognitive and metacognitive strategies (Veenman et al. 2006), and they suggest that the impact of metacognitive self-regulation on comprehension is limited by the characteristics of the cognitive strategy that is trained. Consequently, self-regulation seems to be more important when a strategy is focused on the text itself rather than on its contents. By contrast, when a strategy naturally directs learners to focus on the text contents (as is the case for the visualizing strategy), no further explicit metacognitive control is necessary, and specific training of metacognitive control and self-regulation has no additional benefits for comprehension. The visualizing strategy may intrinsically support mental model building (see De Kooning and Schoot 2013). As noted by Markman (1981), "it is not always necessary to have an explicit question 'Do I understand?' in order to obtain information about one's understanding. ... much information about one's comprehension is a by-product of active attempts to understand and not just of attempts to monitor" (p. 75). The reason for this finding is that the cues that readers use to monitor their comprehension are more likely to focus on the mental model level when the strategy being applied is also focused on the mental model level (e.g., self-explaining by Griffin et al., 2008). Therefore, encouraging students to focus on the mental model level through quality-based monitoring does not generate additional benefits.

Consistent interpretations can be derived for the present results by taking into account learning strategy approaches and the comprehension potential of cognitive strategies. A sole focus on learning strategy approaches makes it difficult to explain why metacognitive control proved to be differentially beneficial depending on the cognitive strategy trained. By considering the comprehension potential of a strategy, a compensatory function of the metacognitive component can be observed. The comprehension potential of a strategy depends on the extent to which it supports mental model building in terms of a representation of what the text is about (Glenberg et al. 1987). It is the visualizing strategy that most directly supports the construction of a coherent representation of what the text is about because the students operate with components that are structurally analogous to their referents. The mapping strategy supports the construction of a coherent propositional representation of explicit text information. Therefore, the learners themselves are responsible for relating the explicit information in their knowledge map to a mental model of the text contents. The highlighting strategy supports the selection of main ideas. Learners themselves are responsible for connecting the main ideas, and further, relating them to a mental model of the text contents. However, learners using the highlighting strategy are not necessarily required to engage in a deep processing of text information; their awareness may skate along the surface of the text (Marton and Säljö 1997). Therefore, explicit metacognitive regulation of strategy use seems to be necessary to foster deeper processing.

From a theoretical perspective, the current results stress the importance of relating learning strategies to basic processes of coherence building in order to pay attention to both the significance of metacognitive self-regulation and the potential of learning strategies to foster comprehension. On the practical side, our results underline the importance of considering not only the quantity of strategy application but also its quality when designing learning strategy interventions. The present research confirms findings from previous studies (Leutner et al. 2007; Schreiber 1998) by showing that training in metacognitive strategy application is helpful for enhancing the quality of learning strategy application.

Finally, some limitations of the present research need to be considered. In all three experiments, we used a science text that described chemical processes and bonds, contained cause-and-effect systems, and focused on complex spatial relations between elements. Thus, our results are limited to this kind of text; additional research is required to extend the text genre and content area. We also used text passages that explained particular scientific concepts in the three types of strategy training. All passages were expository in nature but explained different biology-related concepts that can be found in typical biology text books.

The present studies measured only the comprehension of text contents. However, highlighting training may prove to be beneficial for fostering the retention of text contents (Leutner et al. 2007). In addition, the sample sizes were relatively small; however, each experiment had the statistical power to detect medium to large effects. Furthermore, we focused on high school students with a limited age range. Further research is thus needed to confirm that our results can be generalized across different age groups. Concerning the generalization of the results we would like to point out that our students were explicitly told to apply monitoring and regulation processes when studying the scientific text. Further studies are needed to examine whether students will transfer what they have learned in our training to a new learning situation when they are not specifically told to use their newly acquired skills. Additional research is also necessary to investigate whether quality-oriented monitoring affects metacomprehension accuracy. Such research would provide results on whether monitoring learning performance versus monitoring the quality of strategy application affects how accurately students can assess their comprehension.

Overall, our results indicate that text comprehension can be improved by fostering the quality of learning strategies that focus the learner's attention on the contents of a text. How the quality of strategy application can be measured is still an open question. In our study, we analyzed the students' products of their strategy use—their traces. A promising approach might involve considering not only the students' traces but also the processes by which these traces are generated.

Notes

Author Note

The research presented in this article was funded by the German Research Foundation (DFG; LE 645/6-2).

Appendix 1

Two Example Items from the Multiple-Choice Comprehension Test

What is the chemical basis of hydrogen bonding?

1. (a)

   The polar nature of the water molecule.

2. (b)

   Attraction forces between electrons.

3. (c)

   Attraction forces between ions.

4. (d)

   The polar covalent bond of the water molecule.

What causes the density anomaly of water?

1. (a)

   The ring structure of water molecules when water is freezing

2. (b)

   The surface tension of water.

3. (c)

The open lattice structure of ice crystals.

4. (d)

Hollow spaces in ice crystals.

Appendix 2

Strategy and Self-Regulation Knowledge Items applied in the Highlighting Experiment

Strategy knowledge items

The most important information in a paragraph is... (a) underlined, (b) written down, (c) circled.

Figuring out which pieces of information are important when reading a text depends on ... (a) mainly the reader, (b) the author and the reader, (c) mainly the author.

What is meant by functional side notes (side marks)? (a) abbreviations for text structure elements, (b) statements that are marked by form or color, (c) concepts that emphasize the main ideas of paragraphs, (d) signaling formulations in the text.

What text structure element is involved in or lies behind the following sentence? "Table salt and retail sugar are readily soluble, gypsum and silver chloride are not readily soluble." (a) condition, (b) definition, (c) example, (d) observation.

Which approach is best for the identification of the main concepts and phrases according to the highlighting strategy? (a) following the argumentation of the author, (b) writing down particular text phrases, (c) relating the main concepts to each other.

What text structure element is involved in or lies behind the following sentence? "To increase the temperature of water, a lot of energy in the form of heat is necessary." (a) property, (b) explanation, (c) definition, (d) condition.

What text structure element is involved in or lies behind the following sentence? "Solvents are compared with the solute available in surplus. When water is the solvent, we call this solution an aqueous solution." (a) property, (b) summary, (c) definition, (d) observation.

Self-regulation knowledge items

How should you react to highlighting too much information? (a) write down the most important information, (b) reduce your highlighting, (c) erase your functional side notes.

In which step of the self-regulation strategy do you make a mental note of your progress? (a) first step, (b) second step, (c) third step, (d) fourth step.

What does the following statement refer to? "Did I really first read the paragraph without highlighting words and phrases?" (a) learning strategy, (b) self-regulation, (c) goal setting.

You are applying the self-regulation strategy while highlighting when you … (a) intend to highlight purposeful and sparingly, (b) ask yourself critically whether you have applied the highlighting strategy appropriately, (c) bring to mind the personal benefit of the topic.

When you ask yourself how you applied the highlighting strategy, which steps do you perform? (a) … you are self-observing your strategy application, (b) … you are self-assessing your strategy application, (c) … you are checking your self-assessment.

In the step in which you react, you think about … (a) which steps of the highlighting strategy you have already applied, (b) whether you should further revise your highlighting, (c) whether you have highlighted the main ideas.

Please assign which of the self-regulation steps matches the following example: Daniel thought about whether he had highlighted the most important pieces of information. (a) reacting, (b) self-observing, (c) self-assessing.

References

Alesandrini, K. L. (1981). Pictorial-verbal and analytic-holistic learning strategies in science learning. *Journal of Educational Psychology, 73*, 358–368.
CrossRef (https://doi.org/10.1037/0022-0663.73.3.358)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Pictorial-verbal%20and%20analytic-holistic%20learning%20strategies%20in%20science%20learning&author=KL.%20Alesandrini&journal=Journal%20of%20Educational%20Psychology&volume=73&pages=358-368&publication_year=1981)

Azevedo, R., & Witherspoon, A. M. (2009). Self-regulated learning with hypermedia. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), *Handbook of metacognition in education* (pp. 319–339). Mahwah: Routledge.
Google Scholar (http://scholar.google.com/scholar_lookup?title=Self-regulated%20learning%20with%20hypermedia&author=R.%20Azevedo&author=AM.%20Witherspoon&pages=319-339&publication_year=2009)

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Englewood Cliffs: Prentice-Hall.

Google Scholar (http://scholar.google.com/scholar_lookup?title=Social%20foundations%20of%20thought%20and%20action%3A%20A%20social%20cognitive%20theory&author=A.%20Bandura&publication_year=1986)

Boekaerts, M. (2002). Bringing about change in the classroom: Strengths and weaknesses of the self-regulated learning approach. *Learning and Instruction, 12*, 589–602.
CrossRef (https://doi.org/10.1016/S0959-4752(02)00010-5)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Bringing%20about%20change%20in%20the%20classroom%3A%20Strengths%20and%20weaknesses%20of%20the%20self-regulated%20learning%20approach&author=M.%20Boekaerts&journal=Learning%20and%20Instruction&volume=12&pages=589-602&publication_year=2002)

Chang, K., Sung, Y., & Chen, I. (2002). The effect of concept mapping to enhance text comprehension and summarization. *The Journal of Experimental Education, 71*, 5–23.
CrossRef (https://doi.org/10.1080/00220970209602054)
Google Scholar (http://scholar.google.com/scholar_lookup?title=The%20effect%20of%20concept%20mapping%20to%20enhance%20text%20comprehension%20and%20summarization&author=K.%20Chang&author=Y.%20Sung&author=I.%20Chen&journal=The%20Journal%20of%20Experimental%20Education&volume=71&pages=5-23&publication_year=2002)

Chmielewski, T. L., & Dansereau, D. F. (1998). Enhancing the recall of text: Knowledge mapping training promotes implicit transfer. *Journal of Educational Psychology, 90*, 407–413.
CrossRef (https://doi.org/10.1037/0022-0663.90.3.407)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Enhancing%20the%20recall%20of%20text%3A%20Knowledge%20mapping%20training%20promotes%20implicit%20transfer&author=TL.%20Chmielewski&author=DF.%20Dansereau&journal=Journal%20of%20Educational%20Psychology&volume=90&pages=407-413&publication_year=1998)

Chularut, P., & DeBacker, T. K. (2004). The influence of concept mapping on achievement, self-regulation, and self-efficacy in students of English as a second language. *Contemporary Educational Psychology, 29*, 248–263.
CrossRef (https://doi.org/10.1016/j.cedpsych.2003.09.001)
Google Scholar (http://scholar.google.com/scholar_lookup?title=The%20influence%20of%20concept%20mapping%20on%20achievement%2C%20self-regulation%2C%20and%20self-efficacy%20in%20students%20of%20English%20as%20a%20second%20language&author=P.%20Chularut&author=TK.%20DeBacker&journal=Contemporary%20Educational%20Psychology&volume=29&pages=248-263&publication_year=2004)

Dansereau, D. F., Collins, K. W., McDonald, B. A., Holley, C. D., Garland, J. C., Diekhoff, G., & Evans, S. H. (1979). Development and evaluation of a learning strategy training program. *Journal of Educational Psychology, 71*, 64–73.
CrossRef (https://doi.org/10.1037/0022-0663.71.1.64)
Google Scholar (http://scholar.google.com

/scholar_lookup?title=Development%20and%20evaluation%20of%20a%20learning%20strategy%20training%20program&author=DF.%20Dansereau&author=KW.%20Collins&author=BA.%20McDonald&author=CD.%20Holley&author=JC.%20Garland&author=G.%20Diekhoff&author=SH.%20Evans&journal=Journal%20of%20Educational%20Psychology&volume=71&pages=64-73&publication_year=1979)

Denis, M. (2008). Assessing the symbolic distance effect in mental images constructed from verbal descriptions: A study of individual differences in the mental comparison of distances. *Acta Psychologica, 127*, 197–210.
CrossRef (https://doi.org/10.1016/j.actpsy.2007.05.006)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Assessing%20the%20symbolic%20distance%20effect%20in%20mental%20images%20constructed%20from%20verbal%20descriptions%3A%20A%20study%20of%20individual%20differences%20in%20the%20mental%20comparison%20of%20distances&author=M.%20Denis&journal=Acta%20Psychologica&volume=127&pages=197-210&publication_year=2008)

Denis, M., & Cocude, M. (1989). Scanning visual images generated from verbal descriptions. *European Journal of Cognitive Psychology, 1*, 293–307.
CrossRef (https://doi.org/10.1080/09541448908403090)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Scanning%20visual%20images%20generated%20from%20verbal%20descriptions&author=M.%20Denis&author=M.%20Cocude&journal=European%20Journal%20of%20Cognitive%20Psychology&volume=1&pages=293-307&publication_year=1989)

De Koning, B. B., & van der Schoot, M. (2013). Becoming part of the story! Refueling the interest in visualization strategies for reading comprehension. *Educational Psychology Review, 25*, 261–287.
CrossRef (https://doi.org/10.1007/s10648-013-9222-6)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Becoming%20part%20of%20the%20story%21%20Refueling%20the%20interest%20in%20visualization%20strategies%20for%20reading%20comprehension&author=BB.%20Koning&author=M.%20Schoot&journal=Educational%20Psychology%20Review&volume=25&pages=261-287&publication_year=2013)

Dignath, C., & Buettner, G. (2008). Components of fostering self-regulated learning among students. A meta-analysis on intervention studies at primary and secondary school level. *Metacognition and Learning, 3*, 231–264.
CrossRef (https://doi.org/10.1007/s11409-008-9029-x)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Components%20of%20fostering%20self-regulated%20learning%20among%20students.%20A%20meta-analysis%20on%20intervention%20studies%20at%20primary%20and%20secondary%20school%20level&author=C.%20Dignath&author=G.%20Buettner&journal=Metacognition%20and%20Learning&volume=3&pages=231-264&publication_year=2008)

Dumke, D., & Schäfer, G. (1986). Verbesserung des Lernens aus Texten durch trainiertes Unterstreichen [Improving learning from text by trained underlining]. *Psychologie in Erziehung und Unterricht, 33*, 210–219.
Google Scholar (http://scholar.google.com

/scholar_lookup?title=Verbesserung%20des%20Lernens%20aus%20Texten%20durch%20trainiertes%20Unterstreichen%20%5BImproving%20learning%20from%20text%20by%20trained%20underlining%5D&author=D.%20Dumke&author=G.%20Sch%C3%A4fer&journal=Psychologie%20in%20Erziehung%20und%20Unterricht&volume=33&pages=210-219&publication_year=1986)

Dunlosky, J., Rawson, K. A., Marsh, E., Nathan, M. J., & Willingham, D. T. (2013). Improving students' learning with effective learning techniques: Promising directions from cognitive and educational psychology. *Psychological Science in the Public Interest, 14*, 4–58.
CrossRef (https://doi.org/10.1177/1529100612453266)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Improving%20students%E2%80%99%20learning%20with%20effective%20learning%20techniques%3A%20Promising%20directions%20from%20cognitive%20and%20educational%20psychology&author=J.%20Dunlosky&author=KA.%20Rawson&author=E.%20Marsh&author=MJ.%20Nathan&author=DT.%20Willingham&journal=Psychological%20Science%20in%20the%20Public%20Interest&volume=14&pages=4-58&publication_year=2013)

Ehrlich, K., & Johnson-Laird, P. N. (1982). Spatial descriptions and referential continuity. *Journal of Verbal Learning and Verbal Behavior, 21*, 296–306.
CrossRef (https://doi.org/10.1016/S0022-5371(82)90626-0)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Spatial%20descriptions%20and%20referential%20continuity&author=K.%20Ehrlich&author=PN.%20Johnson-Laird&journal=Journal%20of%20Verbal%20Learning%20and%20Verbal%20Behavior&volume=21&pages=296-306&publication_year=1982)

Ekstrom, R. B., French, J. W., Harman, H. H., & Dermen, D. (1976). *Manual for kit of factor-referenced cognitive tests*. Princeton: Educational Testing Service.
Google Scholar (http://scholar.google.com/scholar_lookup?title=Manual%20for%20kit%20of%20factor-referenced%20cognitive%20tests&author=RB.%20Ekstrom&author=JW.%20French&author=HH.%20Harman&author=D.%20Dermen&publication_year=1976)

Fowler, R. L., & Barker, A. S. (1974). Effectiveness of highlighting for retention of text material. *Journal of Applied Psychology, 59*, 358–364.
CrossRef (https://doi.org/10.1037/h0036750)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Effectiveness%20of%20highlighting%20for%20retention%20of%20text%20material&author=RL.%20Fowler&author=AS.%20Barker&journal=Journal%20of%20Applied%20Psychology&volume=59&pages=358-364&publication_year=1974)

Garner, R. (1981). Monitoring of passage inconsistency among poor comprehenders: a preliminary test of the "piecemeal processing" explanation. *Journal of Educational Research, 73*, 159–162.
CrossRef (https://doi.org/10.1080/00220671.1981.10885302)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Monitoring%20of%20passage%20inconsistency%20among%20poor%20comprehenders%3A%20a%20preliminary%20test%20of%20the%20%E2%80%9Cpiecemeal%20processing%E2%80%9D%20explanation&

author=R.%20Garner&journal=Journal%20of%20Educational%20Research&volume=73&pages=159-162&publication_year=1981)

Gilbert, J. K. (2008). Visualization: An emergent field of practice and enquiry in science education. In J. K. Gilbert, M. Reiner, & M. Nakhleh (Eds.), *Visualization: Theory and practice in science education* (pp. 3–24). Dordrecht: Springer.
CrossRef (https://doi.org/10.1007/978-1-4020-5267-5_1)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Visualization%3A%20An%20emergent%20field%20of%20practice%20and%20enquiry%20in%20science%20education&author=JK.%20Gilbert&pages=3-24&publication_year=2008)

Glenberg, A. M., Meyer, M., & Lindem, K. (1987). Mental models contribute to foregrounding during text comprehension. *Journal of Memory and Language, 26*, 69–83.
CrossRef (https://doi.org/10.1016/0749-596X(87)90063-5)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Mental%20models%20contribute%20to%20foregrounding%20during%20text%20comprehension&author=AM.%20Glenberg&author=M.%20Meyer&author=K.%20Lindem&journal=Journal%20of%20Memory%20and%20Language&volume=26&pages=69-83&publication_year=1987)

Glogger, I., Schwonke, R., Holzäpfel, L., Nückles, M., & Renkl, A. (2012). Learning strategies assessed by journal writing: prediction of learning outcomes by quantity, quality, and combinations of learning strategies. *Journal of Educational Psychology, 104*, 452–468.
CrossRef (https://doi.org/10.1037/a0026683)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Learning%20strategies%20assessed%20by%20journal%20writing%3A%20prediction%20of%20learning%20outcomes%20by%20quantity%2C%20quality%2C%20and%20combinations%20of%20learning%20strategies&author=I.%20Glogger&author=R.%20Schwonke&author=L.%20Holz%C3%A4pfel&author=M.%20N%C3%BCckles&author=A.%20Renkl&journal=Journal%20of%20Educational%20Psychology&volume=104&pages=452-468&publication_year=2012)

Griffin, T. D., Wiley, J., & Thiede, K. W. (2008). Individual differences, rereading, and self-explanation: concurrent processing and cue valididty as constraints on metacomprehension accuracy. *Memory & Cognition, 36,* 93–103.
Google Scholar (https://scholar.google.com/scholar?q=Griffin%2C%20T.%20D.%2C%20Wiley%2C%20J.%2C%20%26%20Thiede%2C%20K.%20W.%20%282008%29.%20Individual%20differences%2C%20rereading%2C%20and%20self-explanation%3A%20concurrent%20processing%20and%20cue%20valididty%20as%20constraints%20on%20metacomprehension%20accuracy.%20Memory%20%26%20Cognition%2C%2036%2C%2093%E2%80%93103.)

Hall, V. C., Bailey, J., & Tillman, C. (1997). Can student-generated illustrations be worth ten thousand words? *Journal of Educational Psychology, 89*, 667–681.
CrossRef (https://doi.org/10.1037/0022-0663.89.4.677)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Can%20student-generated%20illustrations%20be%20worth%20ten%20thousand%20words%3F&author=VC.%20Hall&author=J.%20Bailey&author=C.%20Tillman&journal=Journal%20of%20Educational%20Psychology&volume=89&pages=667-681&publication_year=1997)

Hardy, I., & Stadelhofer, B. (2006). Concept Maps wirkungsvoll als Strukturierungshilfen einsetzen. Welche Rolle spielt die Selbstkonstruktion? [Using concept maps effectively for structuring: the role of self-construction]. *Zeitschrift für Pädagogische Psychologie, 20*, 175–187.
CrossRef (https://doi.org/10.1024/1010-0652.20.3.175)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Concept%20Maps%20wirkungsvoll%20als%20Strukturierungshilfen%20einsetzen.%20Welche%20Rolle%20spielt%20die%20Selbstkonstruktion%3F%20%5BUsing%20concept%20maps%20effectively%20for%20structuring%3A%20the%20role%20of%20self-construction%5D&author=I.%20Hardy&author=B.%20Stadelhofer&journal=Zeitschrift%20f%C3%BCr%20P%C3%A4dagogische%20Psychologie&volume=20&pages=175-187&publication_year=2006)

Hartley, J., Bartlett, S., & Branthwaite, A. (1980). Underlining can make a difference—sometimes. *Journal of Educational Research, 73*, 218–224.
CrossRef (https://doi.org/10.1080/00220671.1980.10885239)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Underlining%20can%20make%20a%20difference%E2%80%94sometimes&author=J.%20Hartley&author=S.%20Bartlett&author=A.%20Branthwaite&journal=Journal%20of%20Educational%20Research&volume=73&pages=218-224&publication_year=1980)

Heller, K. A., & Perleth, C. (2000). *Kognitiver Fähigkeitstest für 4.-12. Klassen, Revision [Cognitive ability test for grades 4-12, revised version]*. Göttingen: Hogrefe.
Google Scholar (http://scholar.google.com/scholar_lookup?title=Kognitiver%20F%C3%A4higkeitstest%20f%C3%BCr%204.-12.%20Klassen%2C%20Revision%20%5BCognitive%20ability%20test%20for%20grades%204-12%2C%20revised%20version%5D&author=KA.%20Heller&author=C.%20Perleth&publication_year=2000)

Hilbert, T. S., & Renkl, A. (2008). Concept mapping as a follow-up strategy to learning from texts: what characterizes good and poor mappers? *Instructional Science, 36*, 53–73.
CrossRef (https://doi.org/10.1007/s11251-007-9022-9)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Concept%20mapping%20as%20a%20follow-up%20strategy%20to%20learning%20from%20texts%3A%20what%20characterizes%20good%20and%20poor%20mappers%3F&author=TS.%20Hilbert&author=A.%20Renkl&journal=Instructional%20Science&volume=36&pages=53-73&publication_year=2008)

Holley, C. D., & Dansereau, D. F. (1984). Networking: The technique and the empirical evidence. In C. D. Holley & D. F. Dansereau (Eds.), *Spatial learning strategies. Techniques, applications, and related issues* (pp. 81–108). New York: Academic.
Google Scholar (http://scholar.google.com/scholar_lookup?title=Networking%3A%20The%20technique%20and%20the%20empirical%20evidence&author=CD.%20Holley&author=DF.%20Dansereau&pages=81-108&publication_year=1984)

Jaccard, J. (1998). *Interaction effects in factorial analysis of variance*. Newbury Park: Sage.
Google Scholar (http://scholar.google.com/scholar_lookup?title=Interaction%20effects%20in%20factorial%20analysis%20of%20variance&author=J.%20Jaccard&publication_year=1998)

Johnson-Laird, P. N. (1983). *Mental models: Towards a cognitive science of language, inference and consciousness*. Cambridge: Cambridge University Press.
Google Scholar (http://scholar.google.com/scholar_lookup?title=Mental%20models%3A%20Towards%20a%20cognitive%20science%20of%20language%2C%20inference%20and%20consciousness&author=PN.%20Johnson-Laird&publication_year=1983)

Kiewra, K. A., Dubois, N., Christensen, M., Kim, S. I., & Lindberg, N. (1989). A more equitable account of the notetaking functions in learning from lecture and from text. *Instructional Science, 18*, 217–232.
CrossRef (https://doi.org/10.1007/BF00053360)
Google Scholar (http://scholar.google.com/scholar_lookup?title=A%20more%20equitable%20account%20of%20the%20notetaking%20functions%20in%20learning%20from%20lecture%20and%20from%20text&author=KA.%20Kiewra&author=N.%20Dubois&author=M.%20Christensen&author=SI.%20Kim&author=N.%20Lindberg&journal=Instructional%20Science&volume=18&pages=217-232&publication_year=1989)

Kintsch, W. (1998). *Comprehension: A paradigm for cognition*. Cambridge: Cambridge University Press.
Google Scholar (http://scholar.google.com/scholar_lookup?title=Comprehension%3A%20A%20paradigm%20for%20cognition&author=W.%20Kintsch&publication_year=1998)

Kosslyn, S. M., Cave, C. B., Provost, D. A., & von Gierke, S. (1988). Sequential processes in image generation. *Cognitive Psychology, 20*, 319–343.
CrossRef (https://doi.org/10.1016/0010-0285(88)90002-3)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Sequential%20processes%20in%20image%20generation&author=SM.%20Kosslyn&author=CB.%20Cave&author=DA.%20Provost&author=S.%20Gierke&journal=Cognitive%20Psychology&volume=20&pages=319-343&publication_year=1988)

Kulhavy, R. W., Lee, J. B., & Caterino, L. C. (1985). Conjoint retention of maps and related discourse. *Contemporary Educational Psychology, 10*, 28–37.
CrossRef (https://doi.org/10.1016/0361-476X(85)90003-7)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Conjoint%20retention%20of%20maps%20and%20related%20discourse&author=RW.%20Kulhavy&author=JB.%20Lee&author=LC.%20Caterino&journal=Contemporary%20Educational%20Psychology&volume=10&pages=28-37&publication_year=1985)

Leopold, C., & Leutner, D. (2002). Der Einsatz von Lernstrategien in einer konkreten Lernsituation bei Schülern unterschiedlicher Jahrgangsstufen [Using learning strategies in a concrete learning situation with students of different grade levels]. *Zeitschrift für Pädagogik, 45*(Supplement), 240–258.
Google Scholar (http://scholar.google.com/scholar_lookup?title=Der%20Einsatz%20von%20Lernstrategien%20in%20einer%20konkreten%20Lernsituation%20bei%20Sch%C3%BClern%20unterschiedlicher%20Jahrgangsstufen%20%5BUsing%20learning%20strategies%20in%20a%20concrete%20learning%20situation%20with%20students%20of%20different%20grade%20levels%5D&author=C.%20Leopold&author=D.%20Leutner&journal=Zeitschrift%20f%C3%BCr%20P%C3%A4dagogik&volume=45&issue=Supplement&pages=240-258&publication_year=2002)

Leopold, C., & Leutner, D. (2012). Science text comprehension: drawing, main idea selection, and summarizing as learning strategies. *Learning and Instruction, 22*, 16–26.
CrossRef (https://doi.org/10.1016/j.learninstruc.2011.05.005)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Science%20text%20comprehension%3A%20drawing%2C%20main%20idea%20selection%2C%20and%20summarizing%20as%20learning%20strategies&author=C.%20Leopold&author=D.%20Leutner&journal=Learning%20and%20Instruction&volume=22&pages=16-26&publication_year=2012)

Leopold, C., Sumfleth, E., & Leutner, D. (2013). Learning with summaries: effects of representation mode and type of learning activity on comprehension and transfer. *Learning and Instruction, 27*, 40–49.
CrossRef (https://doi.org/10.1016/j.learninstruc.2013.02.003)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Learning%20with%20summaries%3A%20effects%20of%20representation%20mode%20and%20type%20of%20learning%20activity%20on%20comprehension%20and%20transfer&author=C.%20Leopold&author=E.%20Sumfleth&author=D.%20Leutner&journal=Learning%20and%20Instruction&volume=27&pages=40-49&publication_year=2013)

Lesgold, A. M., Levin, J. R., Shimron, J., & Guttmann, J. (1975a). Pictures and young children's learning from oral prose. *Journal of Educational Psychology, 67*, 636–642.
CrossRef (https://doi.org/10.1037/0022-0663.67.5.636)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Pictures%20and%20young%20children%E2%80%99s%20learning%20from%20oral%20prose&author=AM.%20Lesgold&author=JR.%20Levin&author=J.%20Shimron&author=J.%20Guttmann&journal=Journal%20of%20Educational%20Psychology&volume=67&pages=636-642&publication_year=1975)

Lesgold, A., McCormick, C., & Golinkoff, R. (1975b). Imagery training and children's prose learning. *Journal of Educational Psychology, 67*, 663–667.
CrossRef (https://doi.org/10.1037/0022-0663.67.5.663)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Imagery%20training%20and%20children%E2%80%99s%20prose%20learning&author=A.%20Lesgold&author=C.%20McCormick&author=R.%20Golinkoff&journal=Journal%20of%20Educational%20Psychology&volume=67&pages=663-667&publication_year=1975)

Leutner, D., Leopold, C., & den Elzen-Rump, V. (2007). Self-regulated learning with a text-highlighting strategy: a training experiment. *Zeitschrift für Psychologie/ Journal of Psychology, 215*, 174–182.
CrossRef (https://doi.org/10.1027/0044-3409.215.3.174)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Self-regulated%20learning%20with%20a%20text-highlighting%20strategy%3A%20a%20training%20experiment&author=D.%20Leutner&author=C.%20Leopold&author=V.%20Elzen-Rump&journal=Zeitschrift%20f%C3%BCr%20Psychologie%2F%20Journal%20of%20Psychology&volume=215&pages=174-182&publication_year=2007)

Leutner, D., Leopold, C., & Sumfleth, E. (2009). Cognitive load and science text

comprehension: effects of drawing and mentally imagining text content. *Computers in Human Behavior, 25*, 284–289.
CrossRef (https://doi.org/10.1016/j.chb.2008.12.010)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Cognitive%20load%20and%20science%20text%20comprehension%3A%20effects%20of%20drawing%20and%20mentally%20imagining%20text%20content&author=D.%20Leutner&author=C.%20Leopold&author=E.%20Sumfleth&journal=Computers%20in%20Human%20Behavior&volume=25&pages=284-289&publication_year=2009)

Mandl, H., & Fischer, F. (Eds.). (2000). *Wissen sichtbar machen. Wissensmanagement mit Mappingtechniken*. Göttingen: Hogrefe.
Google Scholar (http://scholar.google.com/scholar_lookup?title=Wissen%20sichtbar%20machen.%20Wissensmanagement%20mit%20Mappingtechniken&publication_year=2000)

Markman, E. M. (1981). Comprehension monitoring. In W. P. Dickson (Ed.), *Children's oral communication skills* (pp. 61–84). New York: Academic.
Google Scholar (http://scholar.google.com/scholar_lookup?title=Comprehension%20monitoring&author=EM.%20Markman&pages=61-84&publication_year=1981)

Martin, V. L., & Pressley, M. (1991). Elaborative-interrogation effects depend on the nature of the question. *Journal of Educational Psychology, 83*, 113–119.
CrossRef (https://doi.org/10.1037/0022-0663.83.1.113)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Elaborative-interrogation%20effects%20depend%20on%20the%20nature%20of%20the%20question&author=VL.%20Martin&author=M.%20Pressley&journal=Journal%20of%20Educational%20Psychology&volume=83&pages=113-119&publication_year=1991)

Marton, F., & Säljö, R. (1976). On qualitative differences in learning I: outcome and process. *British Journal of Educational Psychology, 46*, 4–11.
CrossRef (https://doi.org/10.1111/j.2044-8279.1976.tb02980.x)
Google Scholar (http://scholar.google.com/scholar_lookup?title=On%20qualitative%20differences%20in%20learning%20I%3A%20outcome%20and%20process&author=F.%20Marton&author=R.%20S%C3%A4lj%C3%B6&journal=British%20Journal%20of%20Educational%20Psychology&volume=46&pages=4-11&publication_year=1976)

Marton, F., & Säljö, R. (1997). Approaches to learning. In F. Marton, D. Hounsell, & N. Entwistle (Eds.), *The experience of learning. Implications for teaching and studying in higher education* (pp. 39–58). Edinburgh: Scottish Academic Press.
Google Scholar (http://scholar.google.com/scholar_lookup?title=Approaches%20to%20learning&author=F.%20Marton&author=R.%20S%C3%A4lj%C3%B6&pages=39-58&publication_year=1997)

Marxen, D. E. (1996). Why reading and underlining a passage is a less effective study strategy than simply rereading the passage. *Reading Improvement, 33*, 88–96.
Google Scholar (http://scholar.google.com/scholar_lookup?title=Why%20reading%20and%20underlining%20a%20passage%20is%20a%20less%20effective%20study%20strategy%20than%20simply%20rereading%20the%20passage&author=DE.%20Marxen&journal=Reading%20Improvement&

volume=33&pages=88-96&publication_year=1996)

Mayer, R. E. (1996). Learning strategies for making sense out of expository text: The SOI model for guiding three cognitive processes in knowledge construction. *Educational Psychology Review, 8*, 357–371.
CrossRef (https://doi.org/10.1007/BF01463939)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Learning%20strategies%20for%20making%20sense%20out%20of%20expository%20text%3A%20The%20SOI%20model%20for%20guiding%20three%20cognitive%20processes%20in%20knowledge%20construction&author=RE.%20Mayer&journal=Educational%20Psychology%20Review&volume=8&pages=357-371&publication_year=1996)

McCagg, E. C., & Dansereau, D. F. (1991). A convergent paradigm for examining knowledge mapping as a learning strategy. *Journal of Educational Research, 84*, 317–324.
CrossRef (https://doi.org/10.1080/00220671.1991.9941812)
Google Scholar (http://scholar.google.com/scholar_lookup?title=A%20convergent%20paradigm%20for%20examining%20knowledge%20mapping%20as%20a%20learning%20strategy&author=EC.%20McCagg&author=DF.%20Dansereau&journal=Journal%20of%20Educational%20Research&volume=84&pages=317-324&publication_year=1991)

Nelson, T. O., & Narens, L. (1994). Why investigate metacognition? In J. Metcalfe & A. P. Shimamura (Eds.), *Metacognition: Knowing about knowing* (pp. 1–25). Cambridge: MIT Press.
Google Scholar (http://scholar.google.com/scholar_lookup?title=Why%20investigate%20metacognition%3F&author=TO.%20Nelson&author=L.%20Narens&pages=1-25&publication_year=1994)

Nicoll, G., Francisco, J., & Nakhleh, M. (2001). A three-tier system for assessing concept map links: a methodological study. *International Journal of Science Education, 23*, 863–875.
CrossRef (https://doi.org/10.1080/09500690010025003)
Google Scholar (http://scholar.google.com/scholar_lookup?title=A%20three-tier%20system%20for%20assessing%20concept%20map%20links%3A%20a%20methodological%20study&author=G.%20Nicoll&author=J.%20Francisco&author=M.%20Nakhleh&journal=International%20Journal%20of%20Science%20Education&volume=23&pages=863-875&publication_year=2001)

O'Donnell, A. M., Dansereau, D. F., & Hall, R. H. (2002). Knowledge maps as scaffolds for cognitive processing. *Educational Psychology Review, 14*, 71–86.
CrossRef (https://doi.org/10.1023/A%3A1013132527007)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Knowledge%20maps%20as%20scaffolds%20for%20cognitive%20processing&author=AM.%20O%E2%80%99Donnell&author=DF.%20Dansereau&author=RH.%20Hall&journal=Educational%20Psychology%20Review&volume=14&pages=71-86&publication_year=2002)

Paris, S. G., Lipson, M. Y., & Wixson, K. K. (1983). Becoming a strategic reader. *Contemporary Educational Psychology, 8*, 293–316.
CrossRef (https://doi.org/10.1016/0361-476X(83)90018-8)

Google Scholar (http://scholar.google.com/scholar_lookup?title=Becoming%20a%20strategic%20reader&author=SG.%20Paris&author=MY.%20Lipson&author=KK.%20Wixson&journal=Contemporary%20Educational%20Psychology&volume=8&pages=293-316&publication_year=1983)

Peterson, S. E. (1992). The cognitive functions of underlining as a study technique. *Reading Research and Instruction, 31*, 49–56.
CrossRef (https://doi.org/10.1080/19388079209558078)
Google Scholar (http://scholar.google.com/scholar_lookup?title=The%20cognitive%20functions%20of%20underlining%20as%20a%20study%20technique&author=SE.%20Peterson&journal=Reading%20Research%20and%20Instruction&volume=31&pages=49-56&publication_year=1992)

Pintrich, P. R. (2000). The role of goal-orientation in self-regulated learning. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *The handbook of self-regulation* (pp. 451–502). San Diego: Academic.
CrossRef (https://doi.org/10.1016/B978-012109890-2/50043-3)
Google Scholar (http://scholar.google.com/scholar_lookup?title=The%20role%20of%20goal-orientation%20in%20self-regulated%20learning&author=PR.%20Pintrich&pages=451-502&publication_year=2000)

Pressley, M., Borkowski, J. G., & Schneider, W. (1989). Good information processing: what it is and how education can promote it. *International Journal of Educational Research, 13*, 857–867.
CrossRef (https://doi.org/10.1016/0883-0355(89)90069-4)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Good%20information%20processing%3A%20what%20it%20is%20and%20how%20education%20can%20promote%20it&author=M.%20Pressley&author=JG.%20Borkowski&author=W.%20Schneider&journal=International%20Journal%20of%20Educational%20Research&volume=13&pages=857-867&publication_year=1989)

Redford, J. S., Thiede, K. W., Wiley, J., & Griffin, T. D. (2012). Concept mapping improves metacomprehension accuracy among 7th graders. *Learning and Instruction, 22,* 262–270.
Google Scholar (https://scholar.google.com/scholar?q=Redford%2C%20J.%20S.%2C%20Thiede%2C%20K.%20W.%2C%20Wiley%2C%20J.%2C%20%26%20Griffin%2C%20T.%20D.%20%282012%29.%20Concept%20mapping%20improves%20metacomprehension%20accuracy%20among%207th%20graders.%20Learning%20and%20Instruction%2C%2022%2C%20262%E2%80%93270.)

Reigeluth, C. M. (1999). The elaboration theory: Guidance for scope and sequence decisions. In C. M. Reigeluth (Ed.), *Instructional-design theories and models. A new paradigm of instructional theory* (pp. 425–453). Mahwah: Erlbaum.
Google Scholar (http://scholar.google.com/scholar_lookup?title=The%20elaboration%20theory%3A%20Guidance%20for%20scope%20and%20sequence%20decisions&author=CM.%20Reigeluth&pages=425-453&publication_year=1999)

Rickards, J. P., & August, G. J. (1975). Generative underlining strategies in prose recall. *Journal of Educational Psychology, 67*, 860–865.

CrossRef (https://doi.org/10.1037/0022-0663.67.6.860)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Generative%20underlining%20strategies%20in%20prose%20recall&author=JP.%20Rickards&author=GJ.%20August&journal=Journal%20of%20Educational%20Psychology&volume=67&pages=860-865&publication_year=1975)

Ruiz-Primo, M. A., & Shavelson, R. J. (1996). Problems and issues in the use of concept maps in science assessment. *Journal of Research in Science Teaching, 33*, 569–600.
CrossRef (https://doi.org/10.1002/(SICI)1098-2736(199608)33%3A6<569%3A%3AAID-TEA1>3.0.CO%3B2-M)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Problems%20and%20issues%20in%20the%20use%20of%20concept%20maps%20in%20science%20assessment&author=MA.%20Ruiz-Primo&author=RJ.%20Shavelson&journal=Journal%20of%20Research%20in%20Science%20Teaching&volume=33&pages=569-600&publication_year=1996)

Rye, J. A., & Rubba, P. A. (2002). Scoring concept maps: an expert-based scheme weighted for relationship. *School Science and Mathematics, 102*, 33–44.
CrossRef (https://doi.org/10.1111/j.1949-8594.2002.tb18194.x)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Scoring%20concept%20maps%3A%20an%20expert-based%20scheme%20weighted%20for%20relationship&author=JA.%20Rye&author=PA.%20Rubba&journal=School%20Science%20and%20Mathematics&volume=102&pages=33-44&publication_year=2002)

Schreiber, B. (1998). *Selbstreguliertes Lernen [Self-regulated learning]*. Münster: Waxmann.
Google Scholar (http://scholar.google.com/scholar_lookup?title=%0A%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20%20Selbstreguliertes%20Lernen%20%5BSelf-regulated%20learning%5D&author=B.%20Schreiber&publication_year=1998)

Schunk, D. H., & Usher, E. L. (2011). Assessing self-efficacy for self-regulated learning. In B. Zimmerman & D. H. Schunk (Eds.), *Handbook of self-regulation of learning and performance* (pp. 282–297). Routledge: New York.
Google Scholar (http://scholar.google.com/scholar_lookup?title=Assessing%20self-efficacy%20for%20self-regulated%20learning&author=DH.%20Schunk&author=EL.%20Usher&pages=282-297&publication_year=2011)

Schwamborn, A., Mayer, R. E., Thillmann, H., Leopold, C., & Leutner, D. (2010). Drawing as a generative activity and drawing as a prognostic activity. *Journal of Educational Psychology, 102*, 872–879.
CrossRef (https://doi.org/10.1037/a0019640)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Drawing%20as%20a%20generative%20activity%20and%20drawing%20as%20a%20prognostic%20activity&author=A.%20Schwamborn&author=RE.%20Mayer&author=H.%20Thillmann&author=C.%20Leopold&author=D.%20Leutner&journal=Journal%20of%20Educational%20Psychology&volume=102&pages=872-879&publication_year=2010)

Schwamborn, A., Thillmann, H., Opfermann, M., & Leutner, D. (2011). Cognitive load and instructionally supported learning with provided and learner-generated

visualizations. *Computers in Human Behavior, 27*, 89–93.
CrossRef (https://doi.org/10.1016/j.chb.2010.05.028)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Cognitive%20load%20and%20instructionally%20supported%20learning%20with%20provided%20and%20learner-generated%20visualizations&author=A.%20Schwamborn&author=H.%20Thillmann&author=M.%20Opfermann&author=D.%20Leutner&journal=Computers%20in%20Human%20Behavior&volume=27&pages=89-93&publication_year=2011)

Simpson, M. L., Olejnik, S., Tam, A. Y., & Supattathum, S. (1994). Elaborative verbal rehearsals and college students' cognitive performance. *Journal of Educational Psychology, 86*, 267–278.
CrossRef (https://doi.org/10.1037/0022-0663.86.2.267)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Elaborative%20verbal%20rehearsals%20and%20college%20students%E2%80%99%20cognitive%20performance&author=ML.%20Simpson&author=S.%20Olejnik&author=AY.%20Tam&author=S.%20Supattathum&journal=Journal%20of%20Educational%20Psychology&volume=86&pages=267-278&publication_year=1994)

Slotte, V., & Lonka, K. (1999). Spontaneous concept maps aiding the understanding of scientific concepts. *International Journal of Science Education, 21*, 515–531.
CrossRef (https://doi.org/10.1080/095006999290552)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Spontaneous%20concept%20maps%20aiding%20the%20understanding%20of%20scientific%20concepts&author=V.%20Slotte&author=K.%20Lonka&journal=International%20Journal%20of%20Science%20Education&volume=21&pages=515-531&publication_year=1999)

Stensvold, M. S., & Wilson, J. T. (1990). The interaction of verbal ability with concept mapping in learning from a chemistry laboratory activity. *Science Education, 74*, 473–480.
CrossRef (https://doi.org/10.1002/sce.3730740407)
Google Scholar (http://scholar.google.com/scholar_lookup?title=The%20interaction%20of%20verbal%20ability%20with%20concept%20mapping%20in%20learning%20from%20a%20chemistry%20laboratory%20activity&author=MS.%20Stensvold&author=JT.%20Wilson&journal=Science%20Education&volume=74&pages=473-480&publication_year=1990)

Stull, A. S., & Mayer, R. E. (2007). Learning by doing versus learning by viewing: three experimental comparisons of learner-generated versus author-provided graphic organizers. *Journal of Educational Psychology, 99*, 808–820.
CrossRef (https://doi.org/10.1037/0022-0663.99.4.808)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Learning%20by%20doing%20versus%20learning%20by%20viewing%3A%20three%20experimental%20comparisons%20of%20learner-generated%20versus%20author-provided%20graphic%20organizers&author=AS.%20Stull&author=RE.%20Mayer&journal=Journal%20of%20Educational%20Psychology&volume=99&pages=808-820&publication_year=2007)

Van Meter, P. (2001). Drawing construction as a strategy for learning form text. *Journal of Educational Psychology, 93*, 129–140.

CrossRef (https://doi.org/10.1037/0022-0663.93.1.129)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Drawing%20construction%20as%20a%20strategy%20for%20learning%20form%20text&author=P.%20Meter&journal=Journal%20of%20Educational%20Psychology&volume=93&pages=129-140&publication_year=2001)

Van Meter, P., & Garner, J. (2005). The promise and practice of learner-generated drawing: literature review and synthesis. *Educational Psychology Review, 17*, 285–325.
CrossRef (https://doi.org/10.1007/s10648-005-8136-3)
Google Scholar (http://scholar.google.com/scholar_lookup?title=The%20promise%20and%20practice%20of%20learner-generated%20drawing%3A%20literature%20review%20and%20synthesis&author=P.%20Meter&author=J.%20Garner&journal=Educational%20Psychology%20Review&volume=17&pages=285-325&publication_year=2005)

Veenman, M. V. J., Van Hout-Wolter, H. A. M., & Afflerbach, P. (2006). Metacognition and learning: conceptual and methodological considerations. *Metacognition and Learning, 1*, 3–14.
CrossRef (https://doi.org/10.1007/s11409-006-6893-0)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Metacognition%20and%20learning%3A%20conceptual%20and%20methodological%20considerations&author=MVJ.%20Veenman&author=HAM.%20Hout-Wolter&author=P.%20Afflerbach&journal=Metacognition%20and%20Learning&volume=1&pages=3-14&publication_year=2006)

Weinstein, C. E., & Mayer, R. E. (1986). The teaching of learning strategies. In M. C. Wittrock (Ed.), *Handbook of research on teaching* (pp. 315–327). New York: Macmillan.
Google Scholar (http://scholar.google.com/scholar_lookup?title=The%20teaching%20of%20learning%20strategies&author=CE.%20Weinstein&author=RE.%20Mayer&pages=315-327&publication_year=1986)

Wiley, J., Griffin, T. D., & Thiede, K. W. (2005). Putting the comprehension in metacomprehension. *The Journal of General Psychology, 132*, 408–428.
CrossRef (https://doi.org/10.3200/GENP.132.4.408-428)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Putting%20the%20comprehension%20in%20metacomprehension&author=J.%20Wiley&author=TD.%20Griffin&author=KW.%20Thiede&journal=The%20Journal%20of%20General%20Psychology&volume=132&pages=408-428&publication_year=2005)

Winne, P. H. (2011). A cognitive and metacognitive analysis of self-regulated learning. In B. Zimmerman & D. H. Schunk (Eds.), *Handbook of self-regulation of learning and performance* (pp. 15–32). Routledge: New York.
Google Scholar (http://scholar.google.com/scholar_lookup?title=A%20cognitive%20and%20metacognitive%20analysis%20of%20self-regulated%20learning&author=PH.%20Winne&pages=15-32&publication_year=2011)

Winne, P. H., & Perry, N. E. (2000). Measuring self-regulated learning. In P. Pintrich,

M. Boekaerts, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 531–566). Orlando: Academic.
CrossRef (https://doi.org/10.1016/B978-012109890-2/50045-7)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Measuring%20self-regulated%20learning&author=PH.%20Winne&author=NE.%20Perry&pages=531-566&publication_year=2000)

Zimmerman, B. J. (2008). Investigating self-regulation and motivation: historical background, methodological developments, and future prospects. *American Educational Research Journal, 45*, 166–183.
CrossRef (https://doi.org/10.3102/0002831207312909)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Investigating%20self-regulation%20and%20motivation%3A%20historical%20background%2C%20methodological%20developments%2C%20and%20future%20prospects&author=BJ.%20Zimmerman&journal=American%20Educational%20Research%20Journal&volume=45&pages=166-183&publication_year=2008)

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Cite this article as:

Leopold, C. & Leutner, D. Metacognition Learning (2015) 10: 313. https://doi.org/10.1007/s11409-014-9130-2

- Received 29 August 2013
- Accepted 28 December 2014
- First Online 23 January 2015
- DOI https://doi.org/10.1007/s11409-014-9130-2
- Publisher Name Springer US
- Print ISSN 1556-1623
- Online ISSN 1556-1631

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