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Kragten, M.

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CHAPTER 5

EFFECT OF A MULTIPLE-STRATEGY TRAINING WITH A STEPWISE WORKING-ROUTINE ON LEARNING FROM PROCESS DIAGRAMS

The present study evaluated the effect of multiple-strategy training on learning from process diagrams. The training focussed on a stepwise working-routine that included when and where to employ cognitive and metacognitive learning strategies and on affective strategies to invest effort in the implementation of this stepwise working-routine. The study followed an experimental pretest-posttest design. Students ($N = 180$) were randomly assigned to the experimental or the control condition. Structured equation modeling was applied to examine the direct and indirect effects, through invested mental effort and perceived task difficulty, on learning from process diagrams. We observed an indirect positive significant effect of multiple-strategy training, through invested mental effort, on learning from process diagrams compared to the control group. We observed no significant direct effect of multiple-strategy training on learning from process diagrams compared to the control group.

1. INTRODUCTION

The adage “A diagram is (sometimes) worth ten thousand words” from Larkin and Simon (1987) implies that diagrams have the potential to communicate efficiently. There is, however, ample evidence that students have difficulties with learning from diagrams (e.g., Chittleborough & Treagust, 2008; Cromley et al., 2013b; Kriz & Hegarty, 2007; Schönborn, Anderson, & Grayson, 2002). Although there is vast amount of research on conditions for learning from diagrams (e.g., Canham & Hegarty, 2010; Kriz & Hegarty, 2007) limited empirical research has been done on the effects of training students to learn from diagrams. The few exceptions are studies by Cromley et al. (2013a; 2013b). Students’ difficulties in learning from diagrams might be explained by insufficient learning strategies and an incoherent and unstable task execution (Kragten, Admiraal, & Rijlaarsdam, in press). The purpose of this study was to evaluate whether learning from diagrams could be facilitated by a multiple-strategy training (Alexander, Graham, & Harris, 1998; Dole, Nokes, & Drits, 2009), including a stepwise working-routine (cf. Souvignier & Mokhlesgerami, 2006).

1.1 Learning strategies

Learning strategies are mental routines or procedures that facilitate learning performance and are potentially conscious and controllable activities (Alexander et al., 1998; Dole et al., 2009; Pressley & Harris, 2006). In their meta-analysis, Donker, De Boer, Kostons, Dignath Van Ewijk, & Van Der Werf (2014) examined the effect of

learning strategy instruction on academic performance, with a focus on improving self-regulated learning (e.g., Boekaerts, 1997; Schunk & Zimmerman, 1997). The authors included studies that aimed at improving cognitive, metacognitive and management (i.e., management of effort, peers and others, and the environment) strategic skills, as well as studies that aimed at improving motivation and metacognitive knowledge. Strategies that focused on improving metacognitive knowledge (i.e., when and where should the strategy be used), and on elaboration, planning, and task value, proved to be most effective. In an earlier meta-analysis, Hattie, Biggs, and Purdie (1996) concluded that best results are obtained when strategy training is metacognitive.

Studies that focused on learning from diagrams identified inference and (activating) prior knowledge as key elements (Canham & Hegarty, 2010; Cook, Carter, & Wiebe, 2008; Cromley, Snyder-Hogan, & Luciw-Dubas, 2009; Cromley et al., 2013a; Kriz & Hegarty, 2007). Prior knowledge affects learning from diagrams because it influences how information is selected and encoded (Canham & Hegarty, 2010; Kriz & Hegarty, 2007); Novices tend to focus on surface features whereas experts focus on thematically relevant information (Cook et al., 2008; Lowe, 1999). Furthermore, learners with more prior knowledge are likely to integrate the encoded graphical representation into a correct mental model (Kriz & Hegarty, 2007; Schnotz & Bannert, 2003). Inferential processes play also a critical role in learning from diagrams (Kriz & Hegarty, 2007). Cromley et al. (2013a) compared the effectiveness of three learning conditions on diagram comprehension. Although students in all conditions improved overall comprehension of diagrams, only students in the two learning conditions that fostered inferential processes improved their scores also on inferential comprehension questions.

1.2 Self-regulated learning

Self-regulated learners effectively employ cognitive and metacognitive learning strategies to achieve their goals. For academic achievement, however, learners also must be motivated to invest mental effort in the employment of learning strategies (Boekaerts, 1997; Paas, Tuovinen, Van Merriënboer, & Darabi, 2005; Pintrich & De Groot, 1990). Hence, a positive relationship likely exists between learner involvement, invested mental effort, and performance.

Azevedo and Cromley (2004) evaluated the effect of training in self-regulated learning on students' learning in a hypermedia learning environment (i.e., nonlinear information presented in multiple modalities). Students in the experimental group received, individually, a 30 minute explanation about several key concepts of self-regulated learning, e.g., planning, monitoring, and strategies; students in the control group did not receive this information. Next, during 45 minutes students studied the human circulatory system in a hypermedia learning environment. Students were instructed to think aloud during the latter phase. Results indicated that the experimental group, compared to the control group, improved their mental models more (students were required to write an essay and draw a diagram) and performed better

on a labelling task (i.e., naming parts of the heart). Verbal protocol data showed that students in the experimental group employed more strategies that indicated self-regulated learning than the control group.

Souvignier & Mokhlesgerami (2006) evaluated the effect of three training programs that aimed at fostering reading strategies and reading comprehension. The training programs of 20 lessons of 45 minutes each were developed within the self-regulated learning framework. They differed with respect to which aspects of strategy instruction were taught: strategy knowledge, cognitive self-regulation, or motivational self-regulation. The training program that incorporated all three aspects started with four lessons on motivational self-regulation (e.g., setting realistic goals), continued with a core strategy program of 12 lessons, and ended with four lessons on cognitive self-regulation. The core strategy program was designed using a 2 (cognitive and metacognitive strategies) x 2 (organization and elaboration) strategy scheme to cover all aspects of reading strategies. In the lessons on cognitive self-regulation, students were trained how to use strategies in a flexible way and offered a working-routine (a “reading plan”) to structure the process of self-regulation during the reading process. Results from the retention test were most promising for the students in the programs that incorporated all three aspects. Only this latter condition outperformed the control group, i.e., students in regular classes, on understanding and application of reading strategies.

1.3 Strategy instruction models

Dole et al. (2009) reported studies distinguishing single-strategy instruction and multiple-strategy instruction models. The present study adapts a multiple-strategy instruction model. Popular multiple-strategy instruction models are reciprocal teaching (Palincsar & Brown, 1984), direct explanation (Duffy et al., 1987), self-regulated strategy development (Harris & Graham, 1996), and transactional strategy instruction (Pressley et al., 1992). After the original studies, these models further developed, which led to some crossover between the models. For instance, in the original work of Palincsar & Brown (1984) on reciprocal teaching, strategies were not explicitly explained to students. However, later studies included explicit teaching of the strategies at the beginning of the training (Rosenshine & Meister, 1994), which is in line with the direct explanation model (Duffy et al., 1987).

The delivery method of most multiple-strategy instruction models includes four steps: 1) explaining the strategies, 2) modeling the strategies, 3) guided practice with feedback while learning to use the strategies, and 4) learners performing the task independently. These steps reflect the social cognitive theoretical model of becoming a self-regulated learner (Schunk & Zimmerman, 1997; Zito, Adkins, Gavins, Harris, & Graham, 2007), in which self-regulated learning is developed through four phases: observational, imitative, self-controlled, and self-regulated. Below we explain the steps of multiple-strategy instruction models in more detail.

With respect to explaining the strategy it is clear that this should be direct and explicit (Pressley, Borkowski, & Schneider, 1989). A learner must be made aware of

what the strategy is about and how to use it. It should also be clear where and when the strategy applies.

With respect to modeling, positive effects have been found on self-efficacy, motivation and academic achievement (Schunk & Zimmerman, 1997). Traditionally, thoughts and motives are verbalized, e.g., by an expert, while performing a task to demonstrate behavior. A recent development in modeling is using eye movement to guide learners' attention during instruction. Jarodzka et al. (2013) used a domain-expert's eye movements and verbal explanation to instruct learners how to perform a perceptual task, i.e., classifying fish locomotion. In this study, there were two experimental conditions of superimposing eye movements on a video, i.e., as a spotlight or as a dot. Students in the spotlight condition (i.e., other information was blurred) increased visual search efficiency. Students in the dot condition (i.e., other information was not blurred) increased interpretation performance. Mason, Pluchino, and Tornatora, (2015) studied the effect of using eye movement modeling on integrative processing and learning from an illustrated text. Lower secondary students in the experimental condition were shown eye movements (without verbal explanation) of a graduate student who modeled how to process an illustrated text. Eye movements modeling had a positive effect on the amount of integrative processing of the illustrated text and—as a result—on recall and transfer posttests, compared to the control condition.

Strategies have to be practiced to become automatized (Pressley et al., 1989). Guided practice can take on a variety of forms but usually consists of teacher or peer feedback on strategy use and behavior and scaffolding. Typically there is a gradual shift in responsibility for the employment of the desired behavior from the teacher to the learner.

Explaining, modeling and guided practice are traditionally delivered by the teacher or through teacher-student interaction. However, computer-based multimedia learning environments are becoming an acceptable alternative to conventional lessons (Lowe & Schnotz, 2008; Kay, 2012). It is, on the other hand, known that students have difficulties with self-regulating their learning with computer-based multimedia environment (Winter, Greene, & Costich, 2008). Delen, Liew, and Willson (2014) examined whether self-regulated learning can be supported by offering learners an enhanced video learning environment. This environment (i.e., the experimental condition) differed from the common video environment (i.e., the control condition) in the function to note-taking, seeking supplemental sources and self-evaluation through practice questions. Students of the experimental condition outperformed students of the control condition on a recall test. The authors attributed the latter result to the effect of the enhanced learning environment on students' engagement and activated self-regulated learning behavior.

1.4 Focus of the present study and research questions

We designed a multiple-strategy training based on the self-regulated strategy development model (Harris & Graham, 1996) to facilitate learning from process dia-

grams. The training specifically focussed on learning from process diagrams; a distinct, but abundantly present, type of diagram that is used in modern science text books to explain processes like photosynthesis, immunology, and protein synthesis (e.g., Reece et al., 2010). Focussing on process diagrams allowed the development of a multiple-strategy training that included specific declarative (e.g., conventions) and procedural knowledge (e.g., where to start, how and when to use the legend). Previous research showed that both types of knowledge distinguished successful learners from less successful learners for this type of diagram (Kragten et al., in press). It has been demonstrated that students benefit from detailed instruction on a specific type of representation (e.g., Körner, 2005). Furthermore, the training was designed for a specific group of students, i.c., pre-university upper secondary school students with an intermediate level of expertise in science. These students are likely to pursue a career in university Science in which they are soon faced with even more challenging process diagrams (Dos Santos & Galembeck, 2015). Hence, facilitating students to learn from process diagrams is an important issue.

The present study's first research question is defined as: "What is the effect of multiple-strategy training on learning from process diagrams?" We expect learners in the multiple-strategy training condition to outperform the control group in learning results.

Two additional research questions are formulated. First, we assume that the training group increases their invested mental effort more than the control group, because the multiple-strategy training is expected to have a positive effect on motivation and/or self-efficacy and thereby increasing willingness to invest mental effort. We also assume that increased invested mental effort is positively related to learning from process diagrams. Therefore, the present study's second research question is defined as: "What is the indirect effect of multiple-strategy training, through invested mental effort, on learning from process diagrams?" We expect that the multiple-strategy training has a positive significant effect on learning results through invested mental effort.

Second, we assume that the training group perceives less task difficulty; the training offers them procedural knowledge and learning strategies that allows them to manage difficulties. An alternative hypothesis could be that perceived task difficulty is inherent to the content of the information presented by the diagram and that there is no effect of multiple-strategy training on perceived task difficulty. In any case, we assume that perceived task difficulty is negatively related to learning from process diagrams, i.e., the more difficult the task is perceived the less is learned. Robinson (2001), for instance, found that students' task performance (i.e., giving verbal directions using a map) was related to perceived task difficulty. Therefore, the present study's third research question is formulated as: "What is the indirect effect of multiple-strategy training, through perceived task difficulty, on learning from process diagrams?"

2. METHOD

2.1 Participants

Participants were 180 students (118 female) from 8 classes from 8 secondary schools in the northwest of the Netherlands. All students were in their last year of pre-university secondary education. They had chosen Biology as a major topic within their exam program with a study load of 480 hours during three years of upper secondary education. The students were in high-performing classes with a focus on Science (i.e., all students also had chosen Chemistry and Math and almost all had chosen Physics).

2.2 Strategy instruction learning environment

The present study follows a pretest-posttest design. A computer-based ‘enhanced’ multimedia learning environment was designed to deliver the instructions for the pretest, intervention, and posttest phase (see Figure 5.1). The multimedia environment is ‘enhanced’ because it contains interactive elements, e.g., built-in stops, tasks and feedback, and user controls (e.g., stop, play, pause, and replay). Students were also provided paper-and-pencil workbooks.



Figure 5.1. Screenshot of the computer-based enhanced multimedia learning environment (original was presented to the training group in Dutch).

This enhanced multimedia environment was designed following the general guidelines for the design of multimedia instructional material (Mayer & Moreno, 2002). Instruction was provided in multiple modalities (i.e., the modality principle)—verbal explanations, minimal text and (animated) illustrations—and were timely coordinated (i.e., temporal contiguity principle). The verbal explanations were in an informal style to enhance engagement (i.e., the personalization principle). The left area of Figure 5.1 continuously presented information that supported the verbal explanation. Parts of the information in the left area that were currently discussed were highlighted (i.e., the signalling principle). In the right area of the learning environment there was always a picture of the lecturer to simulate social presence. The right area also contained two text areas. The text area below the picture of the lecturer signalled the phase of the training, e.g., explaining the strategy; the text area above the lecturer contained keywords. The amount of text was kept to a minimum to avoid redundancy and split-attention effects.

A first version of the enhanced multimedia learning environment and the workbooks was tested in a pilot study with 12 students. The students provided feedback about the content and functionality of the environment and their suggestions were incorporated into a new version. This new version was tested by a high school biology teacher and suggestions were again incorporated into the final version.

2.3 Procedure

The pretest, intervention, and posttest were conducted in one single session in a classroom with computers in students' school. Students were randomly assigned to the experimental condition or the control condition when entering the classroom and were assigned a workplace. Each workplace had an USB stick with the multimedia learning environment, a headphone, general instructions, and the workbooks for the pretest, intervention (training or control tasks), and the posttest. Workplaces were separated by demountable walls to assure privacy. The general instructions were read aloud by the experimenter, i.e., the first author. Next, students' were instructed to start the multimedia learning environment. From that point on, students were led through the pretest, intervention, and posttest phase by instructions in the multimedia learning environment and the workbooks.

2.4 Pretest, intervention, and posttest phase

2.4.1 Pretest phase

The pretest phase consisted of a learning task followed by a test. The learning task was delivered by the multimedia learning environment. Students were presented the following instruction:

“You will be presented a process diagram. Try to understand as much as you can. Study for about 5 minutes. When you are ready you can stop by pressing the spacebar. You will have to complete a test about what you have learned. The process diagram will not be available while you complete the test.”

After instruction, students were presented a process diagram of the absorption and secretion of bile acid and cholesterol in the entero-hepatic cycle (Figure 5.2). Students were supposed to be familiar with parts and function of the entero-hepatic circulation; the basics of the entero-hepatic circulation (i.e., bile is produced by the liver, stored by the gallbladder, excreted to the intestines, and then reabsorbed) had been taught in previous years. Students also were supposed to be familiar with basic chemical reactions and transport processes (e.g., active transport, endocytosis). The detailed biochemical reactions and transport processes of the presented process diagram of the entero-hepatic cycle were not taught previously. Students' task was to learn this new information.

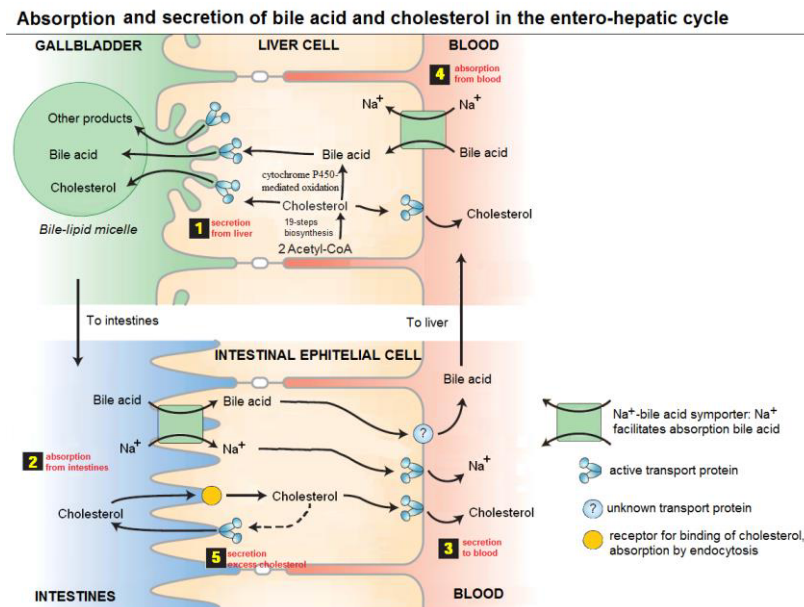


Figure 5.2. Process diagram of the pretest learning task (original diagram was presented to the students in Dutch).

When students finished learning, they pressed the spacebar and got the information how much time they spent on learning from the process diagram; students had to report this on the front page of the pretest workbook. Due to technical problems (e.g., the macro that kept time was not allowed to run by the particular system) and human errors (e.g., students forgot to report the time) we only obtained complete sets (pretest and posttest) of time on learning task data for 110 students.

Then students were instructed to open their pretest workbook. First, students had to rate their invested mental effort and perceived task difficulty on a 7-point rating scale. Self-rating scales on invested mental effort and perceived task difficulty have been used extensively in cognitive load studies (Van Gog & Paas, 2008; for per-

ceived task difficulty see also Robinson, 2001). Students' invested mental effort was assessed by asking: "How much effort did you invest in understanding the diagram?" with 1 as very little and 7 as very much. Perceived task difficulty was assessed by asking: "How difficult was it to comprehend the diagram?" with 1 as very easy and 7 as very difficult. Next, students had to finish the pretest; they were not allowed to adjust their ratings of invested mental effort and perceived task difficulty when they started the pretest. The pretest contained eight multiple-choice items that tested students' knowledge (e.g., "Which transport mechanism is responsible for the absorption of cholesterol in the small intestine?") and comprehension (e.g., "Which statement correctly describes the operation of the Na⁺/bile salt symporter?") of the process diagrams. Each correct item was rewarded with one point.

2.4.2 *Intervention phase*

Students in the experimental condition were presented a multiple-strategy training based on cognitive strategy instruction (Harris & Graham, 1996). The training aimed at teaching students a stepwise working-routine that included when and where to employ cognitive and metacognitive learning strategies. The training consisted of five phases: 1) emphasizing that diagrams are important and useful, 2) explaining the strategic approach, 3) providing a model of the strategic approach, and 4) practicing with the strategic approach, and 5) providing feedback on practicing.

Phase 1. Diagrams are important and useful. This phase started by presenting students a familiar process diagram from their Biology textbook and introducing the subject of the training (i.e., learning from process diagrams). The latter aimed at motivating students for using the strategic approach they are about to learn by showing them a concrete example of a task they often have to perform.

Before students are willing to use a strategy, they have to be convinced that the strategy is effortful, i.e., extra invested mental effort enhances performance, and essential, i.e., one cannot reach competence in a domain without the strategy (Alexander et al., 1998). The continuing information presented in this phase aimed at the latter prerequisites. For this, we informed students that research indicated that diagrams are effective learning tools by briefly explaining, in simple wordings, the multimedia theory (Mayer, 2005), the dual coding principle (Paivio, 1986), and the visual argument (Larkin & Simon, 1987). Furthermore, we stressed that the ability to interpret diagrams is essential in higher education and their future careers. Finally, we informed students that the strategy they are about to learn is based on insights from previous research.

Phase 2. Explaining the strategic approach. In this phase, students were directly informed about the strategic approach for learning from process diagram. The strategic approach was based on findings from research that focussed on strategic text reading (e.g., Pressley & Harris, 2006), inferring (Kriz & Hegarty, 2007), metacognition (e.g., Meijer, Veenman, & Van Hout-Wolters, 2006), and the interpretation of process diagrams (Kragten et al., in press). The working routine of the strategic ap-

proach consisted of four major steps: 1) orientating, 2) finding a starting position, 3) elaborating, and 4) summarizing.

The first step of the working routine (i.e., orientating) consisted of employing activities regarding the meta-information in the process diagram (i.e., title, labels with organisational information, legend). Students were instructed to read the title first and to activate relevant prior knowledge. Next, students were instructed to find and read all labels with information about the organisational level and again to activate relevant prior knowledge. For instance, when a label indicated “liver cell” students might already have some knowledge about processes that take place in that particular cell type. Finally, students had to read the legend items, activate prior knowledge, and find the legend items in the main area of the process diagram. The latter activity was found in a previous study to distinct successful learners from less successful learners (Kragten et al., in press).

The second step was finding a starting position in the main content area of the diagram. In some process diagrams the starting position is clearly indicated. In other diagrams the starting position is not clear and students had to decide where to start reading. For the latter case, students were taught to find a component from where they can go through a large part of the process without going against the flow (i.e., against the direction of the arrows) of the diagram.

The third step of the working routine (i.e., elaborating) consisted of activities that facilitated the students to comprehend the information presented in the main content area of the process diagram. Students were taught to give meaning to every arrow in the content area of the diagram. The multimedia learning environment contained a brief instruction on the most common conventions of arrows in process diagrams (Kragten et al., 2013a; 2015). Knowledge of conventions (Cromley et al., 2013b) and arrows that give meaning to processes (Kragten et al., in press) are important determinants for success in learning from (process) diagrams. Students were also taught to continuously activate prior knowledge, ask questions and make inferences as they proceeded through the main content area of the diagram.

The fourth step of the working routine focussed on the importance summarizing the process as a final stage in learning from a process diagram. Students were instructed to summarize the entire content of the diagram in a few sentences.

Phase 3. Example of the strategic approach. In phase 3, a video was shown where the lecturer modeled the strategic approach (Figure 5.3). In this video, the lecturer was thinking aloud while he was using the strategic approach to learn from a process diagram. The video showed a spotlight to indicate the lecturer’s eye movements. The spotlight was used to guide students’ attention to the part of the diagram that was currently discussed. As discussed earlier, using eye movement to guide learners’ attention facilitates search activities and fosters learning processes (Jarodzka et al., 2013; Mason et al., 2015). The part of the diagram that was not highlighted was slightly darkened but not blurred so that students remained visual access to the entire process diagram. During the video, students had to note the time when the expert passed to a next step of working routine (in Figure 5.3 at 3:47 the lecturer starts with step 3, i.e., elaboration). The latter task aimed at rehearsing the

stepwise working-routine but also at keeping students engaged (Szpunar, Jing, & Schacter, 2014).

Phase 4 and 5. Practicing with the strategic approach and feedback. In phase 4, students practiced using the four steps of the strategy with a new diagram, i.e., the production of stomach acid. The workbook contained tasks to practice each step. For instance, to practice the first step, students were instructed to read the title and report relevant prior knowledge in their workbook. Students were provided feedback by the multimedia learning environment after the tasks of each step; students could request this feedback at their own pace by pressing the spacebar when they finished the tasks of a step.

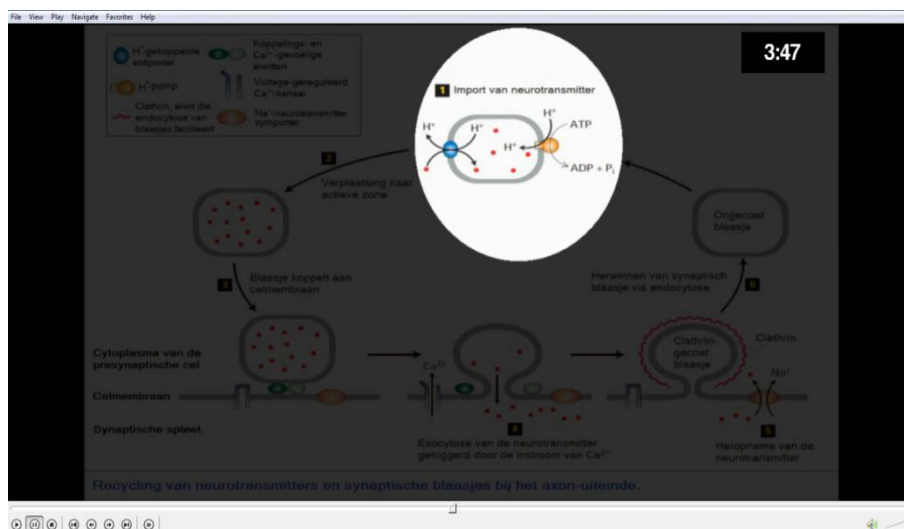


Figure 5.3. Screenshot of the modeling video. The diagram presents the process of the recycling of neurotransmitters and synaptic vesicles at the axon terminal (original version).

At the end of the training, students were instructed to use the strategy they just learned during the posttest phase.

Students in the control condition were presented five process diagrams by the multimedia learning environment. Students had to make a total of nine tasks in their workbook about these process diagrams; the tasks tested if student were able to comprehend the process diagrams. When students finished the tasks, they received feedback (i.e., the correct answers and some further explanations) by the multimedia environment; students in the control condition did not receive any strategic information. Two process diagrams in the control condition were identical to diagrams presented to the students in the experimental condition. The control condition contained three extra process diagrams (with tasks). The latter was based on evaluation of the pilot study and meant to assure that students in both conditions spent an approximate equal amount of time (± 75 min) in the intervention phase.

2.4.3 Posttest phase.

The posttest phase, like the pretest phase, consisted of a learning task followed by a test. The posttest phase started with the same instruction as the pretest phase. After the instruction, students were presented a process diagram that depicted the two main growth modes (autotrophic and heterotrophic) of *Ralstonia eutrophia* (adapted from Pohlmann et al., 2006). Students' task was to study this information. Again, like in the pretest phase, students had to report how much time they spent on learning from the process diagram.

After the learning task, students first had to rate their invested mental effort and perceived task difficulty before they could start with the posttest. The posttest consisted of four subtests. The first two subtests of the posttest consisted of reconstructing the processes of the two main growth modes of *R. eutrophia* by redrawing the components and the arrows. Correct items consisted of the combination of a chemical component and the associated arrow leading away from the chemical component in the right direction (e.g., an arrow depicting passive transport of carbon dioxide into the cell at the autotrophic mode). The subtests that required students to reconstruct the processes of the autotrophic and heterotrophic mode had 13 and 11 scoring items, respectively; each correct item was rewarded with one point. Asking learners to reconstruct a process by drawing is a common procedure to measure students' understanding on a specific topic (Quillin & Thomas, 2015; She & Chen, 2009). The third subtest of the posttest consisted of drawing and naming sub-processes (e.g., the Calvin cycle) and facilitative enzymes (e.g., ATP-synthases). The latter subtest had 5 scoring items. Correct items consisted of correctly naming and drawing a sub-process or an enzyme; each correct item was rewarded with one point. The fourth subtest of the posttest consisted of 10 scoring items; three multiple-choice questions and two open ended questions (answers were scored on 7 elements). Again, each correct item of the latter subtest was rewarded with one point.

2.5 Data analysis

First, we analysed internal reliability, indicated by KR-20, of the pretest and the subtests of the posttest. Once reliable scales were established for the subtests of the posttest, we further examined if these subtests could be presented by a single latent variable within a structured equation model (Figure 4), i.e., the posttest score. Next, descriptive statistics of measures of the pretest and posttest phase were calculated. Furthermore, we conducted a one-way ANCOVA to determine if there was a statistically significant difference between conditions on time on learning task in the posttest phase, controlling for time on learning task in the pretest. We did not include the latter variables into the structured equation model because of missing data as discussed earlier. The outcome of the ANCOVA was used as supportive evidence.

To answer the research questions, a structured equation model (Figure 4) with invested mental effort and perceived task difficulty as mediators, i.e., a multiple mediator model (Preacher & Hayes, 2008), was constructed to evaluate the zero-order (i.e., the direct effect of condition on posttest score without the indirect effects), di-

rect and indirect effect of condition on posttest score. The posttest score was controlled for by the items of the pretest. The effect of experimental condition on invested mental effort in the posttest phase was controlled for invested mental effort in the pretest phase. This allowed us to evaluate the effect of experimental condition on mental effort gain and the effect of mental effort gain on posttest score. The same procedure applied to perceived task difficulty. When both effects of an indirect path were significant, we used the product-of-coefficients approach (Sobel, 1982) to test if the specific indirect effect (Preacher & Hayes, 2008) was significant.

3. RESULTS

3.1 Descriptive statistics

The eight items of the pretest did not converge into a single scale so it was decided to include them separately (*prei1* till *prei8* in Figure 5.4) to the structured equation model to control for posttest score (i.e., latent variable *Postscore* in Figure 5.4). The subtests of the posttest did converge into single scales. Internal reliability, as indicated by KR-20, of the subtests that required students to reconstruct processes of the autotrophic mode and heterotrophic mode was .84 and .82, respectively. Internal reliability, as indicated by KR-20, of the subtest that required students to place and name sub-processes and enzymes was .62. The latter subtest's internal reliability could not be improved by removing items. The subtest that contained multiple choice questions and open ended questions had 10 scoring items and internal reliability, as indicated by KR-20, was .72 after deleting three scoring items. The descriptive statistics of the measures of the pretest and the posttest phase are presented in Table 5.1.

We examined whether the subtest scores of the posttest could be represented by a single latent variable, i.e., the posttest score (i.e., latent variable *Postscore* in Figure 5.4). First, we adjusted the regression weights of *Postscore* for internal reliability of the subtests; the more reliable a subtest is the more it contributes to latent variable *Postscore*.

The correlations (i.e., the standardized regression weights after adjusting for internal reliability) between *Postscore* and scores for reconstructing the autotrophic mode (*postreconauto*), reconstructing the heterotrophic mode (*postreconhetero*), drawing and naming the sub-processes and enzymes (*postenzsub*), and questions (*postquestions*) are $r = .93$, $r = .91$, $r = .79$, and $r = .59$, respectively, and all are significant with $p < .001$. Because all correlations are high we concluded that one single latent variable represents the subtest scores adequately.

There is a significant difference between conditions on time on learning task in the posttest phase controlling for time on learning task in the pretest ($F(2,107) = 10.74$, $p = .001$). This means that students in the experimental condition spent relatively more time on the learning task of the posttest phase, compared to students in the control condition.

Table 5.1. Descriptive statistics of the measures of the pretest and the posttest phase

Phase Variable (<i>short term</i>)	Control group			Training group						
	Obs	M	SD	Min	Max	Obs	M	SD	Min	Max
Pretest phase										
Task difficulty (<i>prei1</i>)	88	4.36	1.25	2	7	92	4.48	1.13	2	7
Mental effort (<i>preme</i>)	88	4.68	1.20	2	7	92	4.88	1.18	2	7
Pretest										
Item 1 (<i>prei1</i>)	88	.56	.50	0	1	92	.42	.50	0	1
Item 2 (<i>prei2</i>)	88	.55	.50	0	1	92	.55	.50	0	1
Item 3 (<i>prei3</i>)	88	.44	.50	0	1	92	.37	.49	0	1
Item 4 (<i>prei4</i>)	88	.59	.49	0	1	92	.58	.50	0	1
Item 5 (<i>prei5</i>)	88	.42	.50	0	1	92	.48	.50	0	1
Item 6 (<i>prei6</i>)	88	.82	.39	0	1	92	.64	.48	0	1
Item 7 (<i>prei7</i>)	88	.53	.50	0	1	92	.42	.50	0	1
Item 8 (<i>prei8</i>)	88	.24	.43	0	1	92	.17	.38	0	1
Learning time (s)	71	190.35	96.34	36	483	72	170.79	77.04	51	409

3.2 Effect of multiple-strategy training on learning from process diagrams

Figure 5.4 presents the unstandardized results of the structured equation model. Posttest score (*Postscore*) was controlled for by items of the pretest; items *prei1* ($B = 1.08, p = .005$), *prei5* ($B = 0.79, p = .050$), and *prei7* ($B = -0.139, p < .001$) significantly predict posttest score (*Postscore*). There is no significant zero-order effect (not shown in Figure 5.4) of condition (*cond*) on posttest score (*Postscore*; $B = 0.34, p > .05$) and no significant direct effect of condition (*cond*) on posttest score (*Postscore*; $B = 0.25, p > .05$). However, the positive regression coefficient of the zero-order effect might suggest there is a trend in the direction of the research hypothesis.

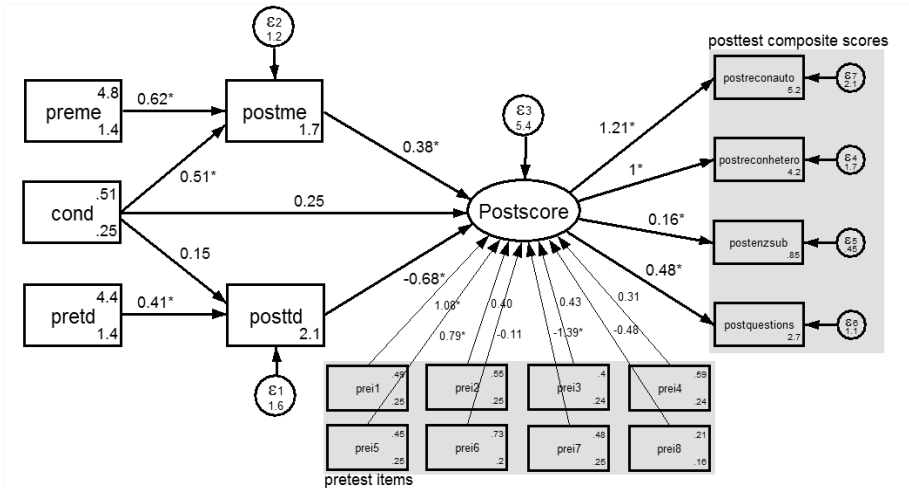


Figure 5.4. Structured equation model.

Note. Unstandardized regression weights are reported. The unstandardized regression weight between *Postscore* and *postreconhetero* is constrained to 1. Means of measured extraneous variables are displayed in the upper right corner and variance is displayed in the lower right corner. Intercepts of endogenous measured variables are displayed in the lower right corner.

Error variances of errors are reported inside the circle below the naming label.

cond = condition (dummy variable, experimental condition = 1); *Postscore*; posttest score; *preme* = pretest mental effort score; *postme* = posttest mental effort score; *pretd* = pretest task difficulty score; *posttd* = posttest task difficulty score; *postreconauto* = posttest reconstruct autotrophic mode score; *postreconhetero* = posttest reconstruct heterotrophic mode score; *postenzsub* = draw and name enzymes and sub-processes score; *postquestions* = posttest questions score; *prei1* to *prei8* = pretest items score.

* $p < .05$.

3.3 Indirect effect of invested mental effort on learning from process diagrams

There is a significant positive effect of condition (*cond*) on posttest invested mental effort score (*postme*; $B = 0.51, p = .002$) controlling for pretest invested mental effort score (*preme*). There is also a significant positive effect of posttest invested mental effort score (*postme*) on posttest score (*Postscore*; $B = 0.38, p = .009$). The indirect positive effect of condition (*cond*) on posttest score (*Postscore*) through posttest invested mental effort score (*postme*) is significant ($B = 0.19$, Sobel test, $z = 2.00, p = .045$).

3.4 Indirect effect of perceived task difficulty on learning from process diagrams

There is no effect of condition (*cond*) on posttest perceived task difficulty (*posttd*; $B = 0.15, p > .05$) controlling for pretest perceived task difficulty (*pretd*). There is a significant negative effect of posttest perceived task difficulty (*posttd*) on posttest score (*Postscore*; $B = -0.68, p < .001$).

4. DISCUSSION

4.1 Effect of multiple-strategy training on learning from process diagrams

We did not observe a zero-order nor a direct effect of multiple-strategy training on learning from process diagrams. A significant zero-order effect, however, is not necessary for an indirect effect (Shrout & Bolger, 2002; Zhao, Lynch, & Chen, 2010); it is possible that there are mediators and suppressors that counterbalance each other (Preacher & Hayes, 2008). The structured equation model of the present study does not contain a suppressor but there are several possible explanations for the total effect to be non-significant. For instance, for some students the training might have increased their lack of confidence in learning from process diagrams; this might be because the training confirmed that they are not successful in learning from process diagrams. The increased lack of confidence could have a negative effect on performance on the posttest and thereby suppress the total effect.

One might consider that not finding a direct effect is due to the design of the multiple-strategy training. An obvious design issue might be the intensity of the multiple-strategy training. The training consisted of one single session of approximately 75 minutes and this might not be enough to have a profound effect on students' ability to employ learning strategies. Interventions aimed at improving strategies are usually much larger with programs consisting of multiple lessons up to programs that last an entire year (Rosenshine & Meister, 1994; Souvignier & Mokhlesgerami, 2006). However, we were dedicated to develop a relatively small training because it would provide a more realistic opportunity for teachers to use the training in classroom. We expected a short but intensive training to be effective because the target group consists of high-performing students with a substantial amount of prior knowledge and experience in learning in Science. Another design issue might be the effectiveness of practicing and feedback in the training. Usually,

specific feedback and guidance is delivered by a teacher until the student is capable of performing the task independently. In the present study, feedback and guidance were provided by the enhanced multimedia learning environment. The feedback was not specific and there was no check whether students were capable of employing the strategic approach without guidance. The direct or indirect effect of the training might increase when the issues mentioned above are addressed in further research.

4.2 Indirect effect of invested mental effort on learning from process diagrams

An indirect effect of condition has been found on learning from process diagrams through invested mental effort. Students in the experimental condition invested more mental effort in the learning task of the posttest phase which had a positive effect on posttest score. The former result might suggest that students were willing to invest more mental effort because of increased strategy belief (Boekaerts, 1997), i.e., a motivational aspect of self-regulated learning. As discussed in the theoretical framework, students must be convinced that a strategy is essential and effortful before they are willing to use it (Alexander et al., 1998). We included several elements in the training that aimed at motivating students to invest more mental effort. For instance, we emphasized why diagrams are important and that elements of the training are based on findings from scientific research. Increased mental effort of students in the experimental condition could also be explained by increased self-efficacy in learning from process diagrams. Students' self-efficacy might have increased because the training facilitated how to learn from process diagrams following a strategic approach. Increased self-efficacy again might have increased students' willingness to invest more mental effort. From a cognitive load perspective (Sweller, 1994) it might be suggested that students' increased mental effort was germane, i.e., it facilitated learning; students who invested more mental effort learned more.

Students in the experimental condition also seemed to spend more time on the learning task in the posttest phase. This suggests that students employed the step-wise strategic approach; it is reasonable to expect that using the approach takes more time. The latter could be considered as supportive evidence for strategy belief (Boekaerts, 1997), i.e., students were willing to invest more time. Due to missing data we did not further explore how invested mental effort and more time on the learning task coincided.

4.3 Indirect effect of perceived task difficulty on learning from process diagrams

No indirect effect of condition was found on learning from process diagrams through perceived task difficulty. Students in the experimental condition did not perceive the posttest task to be more or less difficult than students in the control condition. This suggests that the strategic approach did not increase the complexity of the task by placing extra cognitive demands, neither did it make the diagram easier to understand, compared to the regular instruction condition. The significantly

negative relation of perceived task difficulty with learning from process diagrams was as expected; the more difficult the task was perceived, the lower the score on the posttest (cf. Robinson, 2001).

4.4 Limitations and recommendations for further research

While some limitations have already been discussed we here address a more general issue. We designed a training that used multiple instructional techniques (e.g., modeling, practicing, stepwise working-routine) and taught multiple strategies (e.g., activating prior knowledge, asking questions) to students in the experimental condition. We deliberately designed the training like this because we aimed at a maximum effect by including many elements that were found to be effective for learning. Furthermore, our goal was to design a training that could easily be used by teachers in classroom situations. The enhanced multimedia learning environment would allow teachers to train their students in learning from process diagrams without the need of becoming experts in strategy training. The backdraft of this choice of design is that it is impossible to determine which aspect of the training contributes to an effect or which aspect has to be improved.

We therefore recommend further research to examine the effect of the motivational, cognitive, and metacognitive aspects of the training (cf. Souvignier & Mokhlesgerami, 2006). Further research might also benefit from including more possible mediating variables like self-efficacy, strategy belief, and application of strategies as indicators of an indirect effect. In accordance with Zhao et al. (2010), including possible mediating variables is also a more general recommendation to researchers involved in intervention studies; Including mediators shows which variables are influenced by the intervention and how these variables contribute to the expected effect.

4.5 Conclusion and implication for education

In sum, we found that a multiple-strategy training, in a multimedia learning environment, affects learning from process diagrams positively via increased mental effort. The enhanced multimedia learning environment can easily be used by teachers as a medium for delivering the multiple-strategy training to their students; there were no technical problems running the learning environment on any of the computers of the schools that participated in the present study (except for the time on task macro). The latter and the evidence for its effectiveness suggest that the multiple-strategy training for learning from process diagrams has promising educational purposes.