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Developing and evaluating a strategy for learning from animations

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Abstract

Based on current theories of multimedia learning, we propose a strategy for learning from animations. Two different experimental studies were conducted in order to evaluate the strategy. In the first study, 22 sixth graders learned from an animation without the strategy while 21 students were encouraged to make use of the proposed strategy during learning; use of the strategy was not monitored. The students who were encouraged to take advantage of the strategy learned significantly more than the students who were not asked to do so. In the second study, three groups of sixth graders were investigated. The first group consisted of 49 students who learned from an animation without the strategy. The second group consisted of 52 students who were encouraged to make use of the strategy during learning; but use of the strategy was not monitored. The third group consisted of 53 students who were also encouraged to make use of the strategy during learning and their use of the strategy was monitored. The results of the second study replicated the findings of the first study. Furthermore, learning was most successful when the students' use of the learning strategy was monitored.

Keywords: Animation; Learning; Learning strategy

1. Introduction

Schnotz and Lowe (2008, p. 304) define an animation "… as a pictorial display that changes its structure or other properties over time and which triggers the perception of a continuous change". Very often, animations are combined with spoken texts. In computerised learning environments, animations are frequently employed in order to enhance students' understanding of both complex processes and abstract concepts that change in time and space (Ainsworth & VanLabeke, 2004). For instance, a recent meta-analysis conducted by Höffler and Leutner (2007) revealed that, overall, learning from animations is more successful than learning from static pictures. This is especially true if the displays are both realistic and representational (as opposed to decorational), and if procedural knowledge has to be acquired.

In many cases, however, learning from animation is not more, or even less, successful than learning from other external representations (Bétrancourt, Morrison, & Tversky, 2002; Bétrancourt & Tversky, 2000; Boucheix & Schneider, 2009). Animations, not only offer various opportunities for learning (Bétrancourt, 2005), they also place specific demands on the students' learning processes. For instance, in addition to processing continuously changing information, students need to identify and relate both spatially, as well as temporally, separated components of the pictorial display (cf. Lowe, 1999, 2004, 2008). While many students successfully cope with these demands by systematically processing the presented information (Bétrancourt & Chassot, 2008), others are overburdened and, as a consequence, only superficially process the presented information (Lowe, 2003; Ploetzner, Bodemer, & Neudert, 2008). How can the learning of the less successful students be enhanced? Three different approaches aim to improve students' learning.

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The first approach is the principled design of external representations (cf. Clark & Mayer, 2008; Lowe & Schnotz, 2008; Mayer, 2005).[1] On the basis of theories and models of human learning, this approach essentially aims at designing animations in such a way that the identification and selection, as well as the organisation and integration of information, become as easy as possible for the students. Examples of important design principles are providing learners with control over the pace of the animation (Schwan & Riempp, 2004), combining the animation with spoken text rather than with written text (Moreno & Mayer, 1999), and highlighting relevant components of the pictorial display (Mautone & Mayer, 2001). It was demonstrated in many studies that the principled design of animations facilitates learning. Over the past ten years, research in the cognitive sciences has focused on this approach.

The second approach is the principled design of pedagogical arrangements (cf. Sawyer, 2006). By configuring physical, organisational, and social resources for learning, this approach aims at initiating, sustaining, structuring, supporting, and reflecting upon students' learning activities. Various studies have shown that the principled design of pedagogical arrangements improves learning from animations (Ploetzner, Lippitsch, Galmbacher, Heuer, & Scherrer, 2009). In the past, this approach was emphasised in the educational sciences as well as in the educationally oriented sections of the natural sciences such as biology, chemistry, and physics.

The third approach is the principled design of learning strategies. Also based on theories and models of human learning (e.g., Mayer, 2001; Schnotz & Bannert, 2003), it aims at empowering students to initiate, plan, organise, monitor, and regulate their own learning as well as to competently deal with challenging learning material. With respect to learning from animations, this approach has been largely neglected up until now. However, by analysing the difficulties encountered by students when learning from animations, various researchers have proposed techniques which help to improve students' learning. For instance, Hegarty, Kriz, and Cate (2003) proposed asking students to identify important components and processes within an animation as well as their causal relations. Lowe (2004, 2008) suggested drawing the students' attention (a) to transitions, in which entities appear or disappear within an animation, (b) to transformations, in which the features of entities change, and (c) to translations, in which the positions of entities change. Moreno and Valdez (2005) proposed letting students order and justify arrangements of sub-sequences or single frames within an animation. In a recent study, Huk and Ludwigs (2009) prompted students to reflect and externalise their thoughts while learning from an interactive simulation.

Research on the design of external representations has been successfully coupled with research on the design of learning strategies with respect to learning from texts. Numerous principles have been identified on how to design texts (Ballstaedt, 1997; Gropper, 1991; Jonassen, 1985). These principles address issues such as layout, typography, structure, and style. However, no one assumes that texts designed according to these principles ensure successful learning. Instead, students are taught (from the elementary to the university level) reading and learning strategies which take the specific characteristics of texts into account (Dansereau et al., 1979; Friedrich, 1995; Thomas & Robinson, 1972). These strategies involve both internal learning activities (e.g., paraphrasing text segments, recalling previously learned information) and external learning activities (e.g., highlighting text segments, annotating text segments). Thus, after many years of education, students have acquired and exercised a number of internal and external techniques which help them to systematically approach particularly complex and difficult texts. More recently, research on the design of external representations has also been successfully coupled with research on the design of learning strategies with respect to learning from combinations of texts and illustrations (Ainsworth & Loizou, 2003; Roy & Chi, 2005).

To summarise, analytical as well as empirical research provide valuable insights into three facets of learning from animations: (a) they clarify the potential of animations in the understanding of both complex processes and abstract concepts that change in time and space; (b) they describe the demands that animations place on students' learning processes as well as the difficulties students face in coping with these demands, and (c) they produce various principles for designing animations in order to facilitate students' learning. Up to now, however, research on learning from animations has not yielded any proven strategies that would empower students to systematically and successfully approach animations. In what follows, a strategy for learning from animations based on current theories of multimedia learning is proposed and evaluated. First, the conceptualisation of the strategy is delineated. Thereafter, two experimental studies are presented that were conducted for the evaluation of the proposed strategy.

1.1. Developing a strategy for learning from animations

According to Streblow and Schiefele (2006), a learning strategy is defined as "… (a) a sequence of efficient learning techniques, which (b) are used in a goal-oriented and flexible way, (c) are increasingly automatically processed, but (d) remain consciously applied" (p. 353, translation by the authors). Learning techniques denote specific internal learning activities such as remembering a piece of information and establishing a relation between pieces of information, or external learning activities such as highlighting and annotating segments of a text (Streblow & Schiefele, 2006). If several learning techniques are employed in a coordinated and goal-oriented way, they form a learning strategy.

Learning strategies serve to process information effectively and efficiently, to save information in long-term memory, and to support retrieval of the information (cf. Bannert & Schnotz, 2006). Weinstein and Mayer (1986) distinguished between rehearsal, organisational, and elaboration strategies. While

[1] In accord with Mayer (2001) we consider the design of learning material and learning arrangements as principled, if it is firmly based on theories and models of human learning.

rehearsal strategies are often termed surface strategies, organisational and elaboration strategies are referred to as deep strategies. Marton and Säljö (1984), for example, demonstrated that deep strategies lead to more successful learning than do surface strategies.

Various deep strategies have been designed and evaluated in order to improve students' learning from texts. Prominent examples are the MURDER-Strategy (Mood, Understanding, Recalling, Digesting, Expanding, Reviewing; Dansereau et al., 1979); the PQ4R-Strategy (Preview, Question, Read, Reflect, Recite, Review; Thomas & Robinson, 1972), and the Reduce Text strategy by Friedrich (1995). If successfully evaluated strategies for learning from texts are available while strategies for learning from animations are not, then one approach to conceptualising strategies for learning from animations is to draw upon the strategies for learning from texts. However, strategies for learning from texts cannot be directly mapped onto strategies for learning from animations. Because each representation has its own characteristics and places its own demands on students' learning processes (cf. Ainsworth, 2006), a conceptual model that mediates such a mapping is needed. Current theories of multimedia learning are a promising starting point for formulating the required conceptual model.

Building on Mayer's (1996) model of text comprehension, Mayer's (2001) model of multimedia learning emphasises three different types of cognitive processes: selection, organisation, and integration of information. A fourth type of cognitive process, namely the process of information transformation, is also taken into account; it is, however, less prominent than the aforementioned processes. Selected information is initially processed in separate channels, and two separate models are constructed by organising the selected information: one model for verbal information and one model for pictorial information. Information encoded in the verbal model may be transformed into information encoded in the pictorial model (e.g., by constructing mental images) and vice versa (e.g., by internally verbalising mental images). In order to make multimedia learning successful, the two models need to be related to each other as well as to prior knowledge by means of integration processes. Unlike Mayer (2001), Schnotz and Bannert (2003) propose a so-called integrated model of text and picture comprehension. In their model, verbal and pictorial information are integrated into a single mental model which is neither a verbal nor a pictorial model: it corresponds, rather, to an analogical but modality-unspecific representation.

Prior knowledge forms an important frame of reference during learning. It helps to decide which information is important, to choose adequate forms of information organisation, and to establish appropriate relations between different representations. Therefore, all four types of processes described above may fulfil elaborative functions. Furthermore, while these processes frequently take advantage of prior knowledge during learning, they also contribute to the acquisition of new knowledge which, in turn, might become prior knowledge with respect to subsequent processes.

Thus, in both the model of multimedia learning (Mayer, 2001), as well as in the integrated model of text and picture comprehension (Schnotz & Bannert, 2003), four fundamental types of cognitive processes are assumed to be relevant to learning: selection, organisation, transformation, and integration of information. By means of <u>selection processes</u>, the students choose information from external or internal resources (e.g., selecting information from the learning material or from prior knowledge). Although selection processes may occur throughout the learning process, they are especially important in the early phases of learning.

<u>Organisation processes</u> aim at structuring selected information (e.g., arranging information in a sequence or in a hierarchy). This can be achieved by constructing external representations (e.g., taking notes or drawing a picture) or by constructing internal representations (e.g., building a schema). Organisation processes may also occur throughout the learning process, however, in many models of learning it is assumed that they are especially crucial in the early phases of learning (Mayer, 2001; Schnotz & Bannert, 2003).

<u>Transformation processes</u> denotes that representations are, at least partially, translated to other representations (e.g., translating a verbal statement to a mental image). Transformations might also take place within a certain representational system (e.g., summarising or paraphrasing verbal statements). Transformation processes, however, might repeatedly take place during learning, because they often build upon processes of information selection and organisation, and they seem to be especially fruitful in the later phases of learning.

<u>Integration processes</u> aim at relating verbal and pictorial representations to each other as well as to prior knowledge (Mayer, 2001; Schnotz & Bannert, 2003). While processes of information integration can also repeatedly take place during learning, it is frequently assumed that they are applied to representations resulting from the selection and organisation of information (Mayer, 2001; Schnotz & Bannert, 2003), and thus seem to be more productive in later phases of learning.

By drawing upon strategies for learning from texts as well as current theories of multimedia learning, a strategy for learning from animations can be conceptualised in two steps. Initially, the learning techniques employed in strategies for learning from texts can be categorised according to the cognitive processes which they aim to induce. Subsequently, analogous techniques for learning from animations have to be constructed in such a way that they stimulate the same cognitive processes. For instance, many strategies for learning from texts initially employ techniques which request the students to overview the learning material and to formulate expectations about what can be learned from the material (Thomas & Robinson, 1972). These techniques can also be used when learning from animations.

Specifically, the identification of relevant statements within a text corresponds to the selection of information. The selection of information in animations can be encouraged by techniques such as the identification of important frames within the animation as well as important regions within selected frames. The identification of relations between statements within a text corresponds to the organisation of information. The organisation of information in animations can be supported by techniques such as relating selected frames and regions, as well as selected verbal and pictorial information, to each other. Finally, in order to come up with a coherent mental model of the presented information, the students need to be encouraged to synthesise the established information structures by invoking transformation and integration processes. This can be achieved by means of techniques in which the students are requested to produce descriptions and summaries making use of their own representations (e.g., expressing something verbally in one's own words or pictorially in one's own drawings). The different techniques employed in the strategy that was developed are summarised in Appendix A.

2. Study 1

2.1. Research question – hypotheses

Learning from an animation that was combined with spoken text was investigated in Study 1. The research question was whether students learn more successfully from the animation if they are encouraged to make use of the learning strategy developed. We assumed that the use of the proposed learning strategy systematically induces processes of information selection, organisation, transformation, and integration. Without taking advantage of such a strategy, these processes might take place occasionally, but not systematically. It was, therefore, expected that the students who were encouraged to make use of the learning strategy should learn more successfully than the students who were not encouraged to do so but, instead, wrote a text on what they had learned (Hypothesis 1).

2.2. Method

2.2.1. Design

Two groups of students participated in Study 1. The Essay group learned from the animation without being provided the learning strategy. However, in order to control learning time in a meaningful way, this group had to write an essay on what they learned from the animation. The Strategy group learned from the same animation but was provided with the learning strategy shown in Appendix A. Before and after learning, both groups completed a pre- and a posttest respectively.

2.2.2. Participants

Two complete sixth-grade classes, with a total of 43 students, participated in Study 1. The classes were from a German secondary school (Realschule) in Germany. The students were randomly assigned to the Essay group (8 girls and 14 boys; $M = 12.14$ years, $SD = 0.36$), and to the Strategy group (11 girls and 10 boys; $M = 12.08$ years, $SD = 0.38$).

2.2.3. Material

2.2.3.1. Learning material. The learning material was an animation combined with spoken text that visualises how honey bees dance in order to communicate to other bees where resources in the environment are located. The animation was taken from Microsoft Encarta Professional (Microsoft Corporation, 2002). While one type of dance is used to communicate the location of resources which can be found within 100 m of the honeycomb, a second type of dance is used to communicate the location of resources which are more than 100 m away from the honeycomb. In these dances, honey bees take into account the relative position of the honeycomb, the sun, and the resources. For 2 min and 20 s (30 frames/s), the traces of the honey bees' dances are dynamically visualised and the principles underlying the dances are described both graphically and verbally. The students were able to start, stop, forward, and rewind the animation.

Fig. 1 shows a picture that was included in the animation. In an earlier study, Kombartzky and Ploetzner (2007) demonstrated that learning from the animation was significantly more successful than learning from a sequence of static pictures taken from the same animation.

2.2.3.2. Instructions. Because the participants were sixth graders, the learning techniques shown in Appendix A were expressed as instructions appropriate for students of this age. The students in the Strategy group were requested to process the animation according to the following instructions, presented on a worksheet, and to take notes on it. (a) Observe the complete animation and note on the worksheet what you expect to learn from it. (b) Observe the animation again. Identify between four to six important pictures and sketch them on the worksheet. (c) Listen closely to the spoken explanations and write down the explanatory statements next to each of your sketches. (d) Circle, using different colours, important words in each of your explanatory notes as well as important regions in your sketches. (e) Label the circled regions in the sketches. (f) Describe in written form the relationships between the sketches and the explanatory notes using your own words. (g) Read through all of your explanatory notes and take a look at the associated sketches. In your own words, describe the dance of the honey bee.

The students in the Essay group were requested to describe in an essay how honey bees communicate by means of dances. They were asked to describe the principles of the dances as detailed as possible so that somebody who did not watch the animation, nevertheless, can understand the principles.

2.2.4. Measures

2.2.4.1. Pre- and posttest. According to Anderson and Krathwohl (2001), one can distinguish four different knowledge levels of increasing complexity: (a) factual knowledge, (b) conceptual knowledge, (c) procedural or rule-based knowledge, and (d) meta-cognitive knowledge. Factual knowledge denotes declarative knowledge about isolated entities. According to Anderson and Krathwohl (2001), the main mechanism to acquire factual knowledge is remembering. Conceptual knowledge stands for declarative knowledge about the relationships between different entities at various levels of abstraction. The main mechanisms to acquire conceptual knowledge are abstraction and understanding.

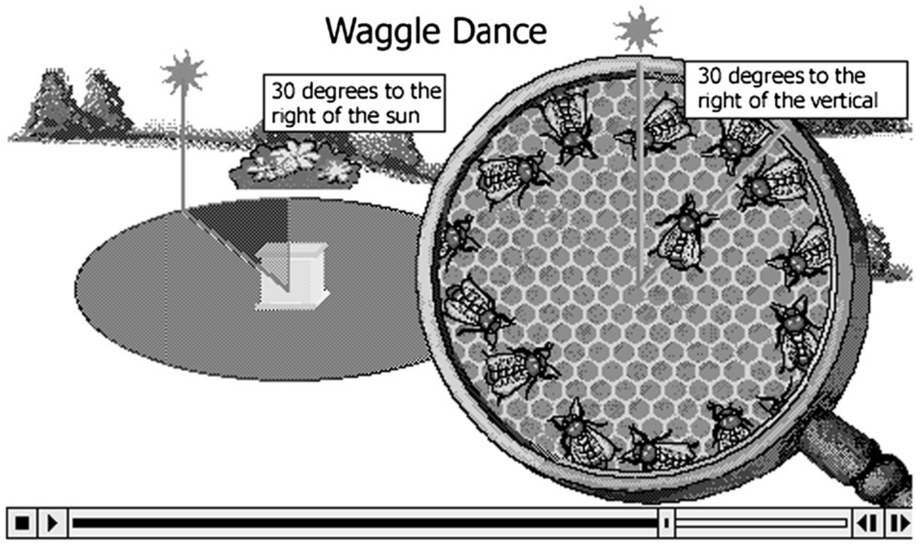

Fig. 1. A screen shot taken from the animation (reproduction of the screen shot with friendly permission of Microsoft Corporation; translation by the authors).

Procedural or rule-based knowledge is constituted by the principles and rules of how to make use of facts and concepts given a specific situation or problem. The main mechanisms to acquire rule-based knowledge are problem solving and knowledge transfer. Finally, meta-cognitive knowledge denotes knowledge about the properties of one's own knowledge such as its correctness, completeness and scope of applicability. The acquisition of meta-cognitive knowledge requires much experience and reflection in a knowledge domain. Because it cannot be expected that meta-cognitive knowledge is acquired during a short period of learning, we did not include it in our assessments.

Because it was expected the students to have minimal prior knowledge about how honey bees dance in order to communicate with other bees, their prior knowledge was assessed in the pretest only at the factual knowledge level by means of six questions. The posttest comprised 24 questions, that is, eight questions assessed factual knowledge, eight questions assessed conceptual knowledge, and eight questions assessed rule-based knowledge. Examples of questions from the posttest addressing the different kinds of knowledge are shown in Appendix B. Each correct response was scored with 0.5.

The maximum score achievable for pretest was 6.5, because three of the six questions were made up of several subquestions. Internal consistency of the pretest was Cronbach's $\alpha = 0.32$.

The posttest measures were scored by two independent raters. Interrater reliability was ICC(3, k) $= 0.99$ for factual knowledge, ICC(3, k) $= 0.99$ for conceptual knowledge, and ICC(3, k) $= 0.97$ for rule-based knowledge. The few differences in the two ratings were jointly settled by the raters. Overall internal consistency of the posttest was Cronbach's $\alpha = 0.71$.

2.2.5. Procedure

The students were tested in groups. Initially, they worked individually on the pretest. Thereafter, a short introduction was given to the students describing the phenomenon that shortly after a honey bee has located a resource many other bees appear in order to exploit the resource. After the introduction was finished, the students in the Essay group watched the animation. They then wrote an essay on what they had learned. The students in the Strategy group received a short introduction on how to take advantage of the learning strategy. The instructions described in subchapter 2.2.3.2 were presented to the students on a worksheet. Afterwards, the students worked through this worksheet while watching the animation. Students' use of the learning strategy was not monitored.

The Essay group worked for 60 min on the learning material and the Strategy group worked, on average, for 64 min (minimum 35 min, maximum 75 min) on the learning material. While working on the learning material, the students in both groups did not receive any further support by the instructor.

2.3. Results

Overall, the Essay group ($M = 1.37$ (21.07%), SD $= 0.61$) and the Strategy Group ($M = 1.13$ (17.38%), SD $= 0.78$) possessed only little prior knowledge. Because there were no significant differences between the two groups on the pretest, $t(1, 41) = 1.14$, $p = 0.26$, and an ANCOVA showed that prior knowledge did not significantly influence the posttest results, $F(3, 38) = 2.18$, $p = 0.10$, prior knowledge was not included in the analysis of the posttest results. The descriptive statistics of the posttest data are shown in Table 1.

The results of a 2 (group) × 3 (posttest) MANOVA revealed a significant main effect of group at the multivariate level, Wilks's $\lambda = 0.72$, $F(3, 39) = 4.94$, $p < 0.01$, partial $\eta^2 = 0.27$. Moreover, two of the univariate F-tests showed a significant main effect of group, for conceptual knowledge, $F(1, 41) = 5.15$, $p < 0.05$, partial $\eta^2 = 0.11$, as well as for rule-based knowledge, $F(1, 41) = 14.04$, $p < 0.01$, partial $\eta^2 = 0.25$. The corresponding effect sizes were medium to large. With respect to factual knowledge, the group effect was

Table 1
The absolute and relative means (M), as well as standard deviations (SD), with respect to each kind of knowledge assessed in the posttest.

Group	Factual knowledge		Conceptual knowledge		Rule-based knowledge	
	M	SD	M	SD	M	SD
Essay	2.63 (65.75%)	0.96	2.11 (52.75%)	1.11	1.29 (32.25%)	0.58
Strategy	3.07 (76.75%)	0.72	2.78 (69.50%)	0.78	2.14 (53.50%)	0.87

not significant, $F(1, 41) = 2.76$, $p = 0.10$. Thus, the Strategy group was significantly more successful than the Essay group at acquiring both conceptual knowledge and rule-based knowledge (see Table 1).

2.4. Discussion

As Hypothesis 1 predicted, the Strategy group exhibited much more successful learning than did the Essay group. In particular, the learning strategy seems to be more supportive as the knowledge to be acquired becomes more demanding. While the acquisition of factual knowledge from animations was accomplished without the need of the learning strategy, the acquisition of conceptual and rule-based knowledge was improved by taking advantage of the learning strategy.

Because this study was the first evaluation of the proposed strategy, the question arose as to whether or not the observations made could be replicated again. Furthermore, an analysis of the students' worksheets revealed that only 19% of the students drew all of the sketches required and took all of the notes as instructed on the worksheet. Therefore, it is possible that many students did not fully exploit the strategy instructed, and that learning could be further improved by monitoring the students' use of the strategy.

3. Study 2

3.1. Research questions – hypotheses

In the second study, two research questions were addressed. First, can the results of the first study be replicated with a new sample of students? Second, can learning from animations be enhanced when the use of the learning strategy is monitored? As in Study 1, it was assumed that the use of the proposed learning strategy systematically induces processes of information selection, organisation, transformation, and integration. It was, therefore, expected that the students who were encouraged to make use of the learning strategy should learn more successfully than those who were not encouraged to do so, that is the Essay group (Hypothesis 1).[2] If the use of the strategy is monitored, the cognitive processes should take place even more systematically. It was, therefore, expected that the students whose use of the strategy was monitored should learn more successfully than those whose use of the strategy was not monitored (Hypothesis 2).

[2] This is the same hypothesis as in Study 1 and, therefore, it was labelled Hypothesis 1.

3.2. Method

3.2.1. Design

Three groups of students were investigated. As in Study 1, the Essay group learned from the animation without being provided the learning strategy. However, in order to control learning time in a meaningful way, this group had to write an essay on what they learned from the animation. As in Study 1 as well, the Strategy group learned from the same animation but was provided with the learning strategy shown in Appendix A. The Monitored Strategy group also learned from the same animation and was also provided with the learning strategy shown in Appendix A. In this group, however, the use of the strategy was monitored to a certain degree. Before and after learning, all groups completed a pre- and a posttest respectively.

3.2.2. Participants

Five complete sixth-grade classes, with a total of 154 students, participated in Study 2. The classes were from a German secondary school (Realschule). The students were randomly assigned to three groups, that is, the Essay group (20 girls and 29 boys; $M = 12.20$ years, $SD = 0.35$), the Strategy group (23 girls and 29 boys, $M = 12.15$ years, $SD = 0.22$), and the Monitored Strategy group (26 girls and 27 boys, $M = 12.15$ years, $SD = 0.51$).

3.2.3. Material

Both the learning material and the learning strategy were the same as in Study 1. In Study 2, the students' prior knowledge was assessed at the factual knowledge level by means of eight questions. These questions were identical to the questions assessing factual knowledge in the posttest. The posttest was the same as the one used in Study 1. There were three posttest measures, that is, factual knowledge, conceptual knowledge, and rule-based knowledge. Each correct response was scored with 0.5. The maximum score achievable for the pretest was 4.0. Internal consistency of the pretest was Cronbach's $\alpha = 0.28$.

The posttest measures were scored by two independent raters. Interrater reliability was $ICC(3, k) = 0.99$ for factual knowledge, $ICC(3, k) = 0.99$ for conceptual knowledge, and $ICC(3, k) = 0.98$ for rule-based knowledge. The few differences in the two ratings were jointly settled by the raters. Overall reliability of the posttest was Cronbach's $\alpha = 0.58$.

3.2.4. Procedure

The students were tested in groups. Initially, the students worked individually on the pretest. Thereafter, the same introduction was given to the students as in the first study.

After the introduction was finished, the students in the Essay group learned from the animation. They then wrote an essay on what they had learned. The students in the Strategy group, as well as those in the Monitored Strategy group, received a short introduction on how to take advantage of the learning strategy. In the Strategy group, the students received a worksheet which contained all seven instructions described above at once. Afterwards, the students worked through this worksheet while learning from the animation. In the Monitored Strategy group, the students received one instruction at a time on a worksheet. Only after presenting a processed instruction to the experimenter did they receive the next instruction. Instructions that were processed could be kept by the students. The experimenter monitored whether the students' worksheet showed any acceptable processing of the instruction. The experimenter did not monitor the quality of the processing. The Essay group worked for 60 min on the learning material. The Strategy group and the Monitored Strategy group worked for 65 min on the learning material. While working on the learning material, the students in all groups did not receive any further support by the instructor.

3.3. Results

The Essay group ($M = 0.40$ (10.00%), SD = 0.34), the Strategy group ($M = 0.50$ (12.50%), SD = 0.29), and the Monitored Strategy group ($M = 0.50$ (12.50%), SD = 0.31) possessed only little prior knowledge. Because there were no significant differences between the groups on the pretest, $F(2, 151) = 1.52$, $p = 0.22$, and an ANCOVA showed that prior knowledge did not significantly influence the posttest results, $F(3, 148) = 1.07$, $p = 0.36$, prior knowledge was not included in the analysis of the posttest results. The descriptive statistics of the posttest data are shown in Table 2.

A 3 (group) × 3 (posttest) MANOVA revealed a significant main effect of group at the multivariate level, Wilks's $\lambda = 0.72$, $F(6, 298) = 7.93$, $p < 0.001$, partial $\eta^2 = 0.13$. Moreover, two of the univariate tests showed a significant main effect of group for conceptual knowledge, $F(2, 151) = 16.45$, $p < 0.001$, partial $\eta^2 = 0.17$, as well as for rule-based knowledge, $F(2, 151) = 13.35$, $p < 0.001$, partial $\eta^2 = 0.15$. The corresponding effect sizes were again medium to large. With respect to factual knowledge, statistical significance was missed only marginally, $F(2, 151) = 3.05$, $p = 0.05$, partial $\eta^2 = 0.03$, but the effect size was low.

To further analyse the learning performances of the different groups, we conducted planned contrasts with respect to both conceptual knowledge and rule-based knowledge. Two contrasts compared the combined learning performances of the two Strategy groups to the learning performance of the Essay group. The Strategy groups significantly outperformed the Essay group with respect to both conceptual knowledge, $t(1, 151) = -5.33$, $p < 0.001$, Cohen's $d = -0.86$, and rule-based knowledge, $t(1, 151) = -4.34$, $p < 0.001$, Cohen's $d = -0.70$. Two more contrasts compared the learning performance of the Monitored Strategy group to the learning performance of the Strategy group. The Monitored Strategy group significantly outperformed the Strategy group with respect to conceptual knowledge $t(1, 103) = -2.03$, $p < 0.05$, Cohen's $d = -0.40$, as well as rule-based knowledge, $t(1, 103), = -2.75$, $p < 0.01$, Cohen's $d = -0.54$.

3.4. Discussion

As in Study 1, the Strategy group exhibited more successful learning than did the Essay group (Hypothesis 1). As hypothesised (Hypothesis 2), the best learning performance was shown by the Monitored Strategy group. By means of monitoring, the students in this group were pushed to more completely externalise their processing of the learning techniques on the worksheet; this further improved the students' learning.

While in Study 1 only 19% of the students in the Strategy group drew all of the sketches and took all the notes as instructed on the worksheet, in Study 2 almost 77% of the students in the Strategy group did so. Thus, in Study 2 the students in the Strategy group externalised the results of using the learning techniques much more completely than the students did in Study 1. We do not know why the students in the Strategy groups behaved so differently in the two studies. On the one hand, it could be, for example, that the students in the second study took more notes on the worksheet because they were more accustomed to following structured worksheets, or because they were more committed to their teacher. On the other hand, taking more notes on the worksheet does not necessarily mean that the intended cognitive processes were conducted more frequently and more thoroughly. In future studies it needs to be investigated how the students' externalisations are related to their learning success. Study 2, nevertheless, demonstrated that learning can be improved if the use of the strategy is strongly encouraged.

4. General discussion

Learning from animations can be supported in a variety of ways. For example, by improving the design of animations; by providing physical, organisational, and social resources that

Table 2
The absolute and relative means (M), as well as standard deviations (SD), with respect to each kind of knowledge assessed in the posttest.

Group	Factual knowledge		Conceptual knowledge		Rule-based knowledge	
	M	SD	*M*	SD	*M*	SD
Essay	2.50 (62.50%)	0.81	1.75 (43.75%)	0.80	1.35 (33.75%)	0.81
Strategy	2.45 (61.25%)	0.74	2.37 (59.25%)	0.82	1.75 (43.75%)	0.93
Monitored Strategy	2.81 (70.25%)	0.87	2.72 (68.00%)	0.94	2.20 (55.00%)	0.72

initiate, sustain, and support learning from animations; and by empowering learners to successfully cope with the demands of animations. The research presented in this paper focuses on the latter approach. Starting from current theories of multimedia learning, we developed a strategy for learning from animations. We evaluated the proposed strategy in two experimental studies. In both studies we demonstrated that the proposed learning strategy is suitable for improving learning from animations. The strategy was more supportive as the levels of knowledge to be acquired became more demanding.

However, there is much potential for further research on strategies for learning from animations. For instance, a learning strategy can be provided to the students in many different ways. In our studies, all the different learning techniques to be applied were presented to the students on a worksheet. A different approach could have been, for example, to prompt the students incrementally and adaptively for single learning techniques while they are working on specific parts of the learning material. On the one hand, prompting students incrementally and adaptively could prove to be more beneficial to learning than is providing students with a worksheet because this method encourages the use of a learning technique directly when it is needed (cf. Davis & Linn, 2000; Swanson, 1999). On the other hand, incremental and adaptive prompting is costly because it demands the close monitoring of a student's learning either by a human or by a computer.

In general, the procedure that was implemented in the two studies is appropriate in order to demonstrate that the different learning techniques are principally beneficial. In the long run, however, one needs to investigate whether the learning strategy can be taught to students in such a way that the students internalise the strategy step by step and can then automatically apply it to new animations with success. Commonly, this requires the training of a learning strategy over a longer period of time. Research indicates that the use of a newly acquired but not yet automatised learning strategy demands a great deal of mental effort and might therefore – temporarily – even impede learning (Bjorklund & Coyle, 1995). Only after a longer period of training does it become easier to apply the strategies, hence learning improves.

There might also be potential for optimising the proposed strategy. On the one hand, we need to better understand how the learning techniques employed in the strategy contribute to learning success. Are the learning techniques of equal importance, or could some of the learning techniques be neglected? On the other hand, only processes at the cognitive level are currently induced by means of the strategy. Various studies, however, indicate that learning might be even more successful if processes at the meta-cognitive level were also taken into account (Bannert, 2007; Leutner & Leopold, 2006; Pintrich, 2000; Vovides, 2008). It could therefore be of value to further investigate whether it is beneficial to complement the proposed learning techniques at the cognitive level with learning techniques at the meta-cognitive level.

Last but not least, the question arises as to whether the results we found in our studies can be generalised to other learning settings. It needs to be investigated whether the proposed strategy also supports learning from other kinds of animations. The proposed strategy has been developed for learning from animations which are combined with spoken text. If animations are combined with written texts, one of the learning techniques employed within the strategy would become superfluous: Identifying and taking notes of important 'spoken' statements. If animations are not combined with spoken or written texts, the strategy would require even more modifications. Furthermore, in our studies we took advantage of an animation that could be controlled by the students. If students need to learn from an animation that they cannot control, a completely different strategy is needed. It is also not clear whether the proposed strategy would be appropriate for learning from animations which encompass other kinds of representations. For instance, in the natural sciences such as biology, chemistry, and physics, animations are often employed which visualise scientific concepts and their relationships by means of graphical, but nevertheless, abstract representations (Ainsworth & Van Labeke, 2004; Ploetzner, Lippitsch, Galmbacher, Heuer, & Scherrer, 2009). The question remains open as to whether the proposed strategy would be appropriate for supporting students' understanding of these abstract representations. Future research might identify learning techniques that are applicable to a wide range of animations as well as learning techniques that are specific to certain types of animation. This research would not only advance our understanding of learning strategies and techniques, but also our understanding of animations and their characteristics.

A further question to be addressed in the future is which students actually benefit from the proposed strategy. It could be, for instance, that students with low cognitive abilities benefit more from the strategy than students with high cognitive abilities. Perhaps the learning of students with high cognitive abilities is, in the sense of an aptitude-treatment interaction, even impeded if they are requested to make use of such a strategy (cf. Hegarty & Kriz, 2008). It also needs to be investigated whether older students, in particular, would also benefit from making use of the proposed strategy. Research on learning strategies indicates that the older the students get, the more they make use of learning techniques that they were taught or which they acquired on their own during their learning experiences (Artelt, 2000). Although individually acquired techniques might not be optimal, their use is often highly automatised and might therefore conflict with new learning techniques that are presented to the students. In these cases, longer periods of training are necessary until the students refrain from making use of the old learning techniques and spontaneously take advantage of the new ones.

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Appendix A. The learning techniques employed in the strategy for learning from animations per cognitive process

1. Orientation and development of expectations:
   Observing the animation and formulating expectations
2. Selection and organisation:
   Identifying and sketching important frames
   Identifying and taking notes of important statements
   Identifying and marking important regions in the frames
   Identifying and marking important phrases in the statements
   Labelling regions in the frames
3. Transformation and integration
   Expressing relations between frames and statements in one's own words
   Summarising the displayed process in one's own words

Appendix B. Three sample questions from the posttest

1. Example of a question addressing factual knowledge: "Honey bees communicate the location of resources to other bees. Name two possibilities of how bees communicate with other bees."
2. Example of a question addressing conceptual knowledge: "In the picture on the left hand side, you see the position of the comb, the resource, and the sun. In the picture on the right hand side, draw how the honey bee will dance on the comb in order to communicate the location of the resource to other bees."
3. Example of a question addressing rule-based knowledge: "The comb and the resource remain at the same location, however, the position of the sun changes during the day. What is the time of day when the honey bee performs each of the two dances shown in the pictures below?"

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