Enabling, Facilitating, and Inhibiting Effects of Animations in Multimedia Learning: Why Reduction of Cognitive Load Can Have Negative Results on Learning

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New technologies allow the display of text, static visuals, and animations. Although animations are inherently attractive, they are not always beneficial for learning. Problems may arise especially when animations modify the learner's cognitive load in an unintended way. In two learning experiments with 40 and 26 university students, the effects of animated pictures on knowledge acquisition were investigated. Some pictures displayed visual simulations of changes over time, whereas other pictures could be manipulated by learners to represent different states in time. Results showed that manipulation pictures had an enabling function for individuals with high learning prerequisites, whereas simulation pictures had a facilitating function for individuals with low learning prerequisites. However, the facilitating function was not beneficial for learning, because learners were prevented from performing relevant cognitive processes on their own. A careful analysis of the interrelation between different kinds of cognitive load and the process of learning is therefore required.

☐ Computer-based multimedia learning environments can provide rapid access to information. They can display multiple representations, and they can enhance active learning through interactivity and exploration. However, these learning environments can also introduce new demands for learners. In many environments learners have to orient themselves and to navigate within complex information spaces. They have to search for and evaluate information, and they have to understand and integrate multiple representations to build coherent knowledge structures.

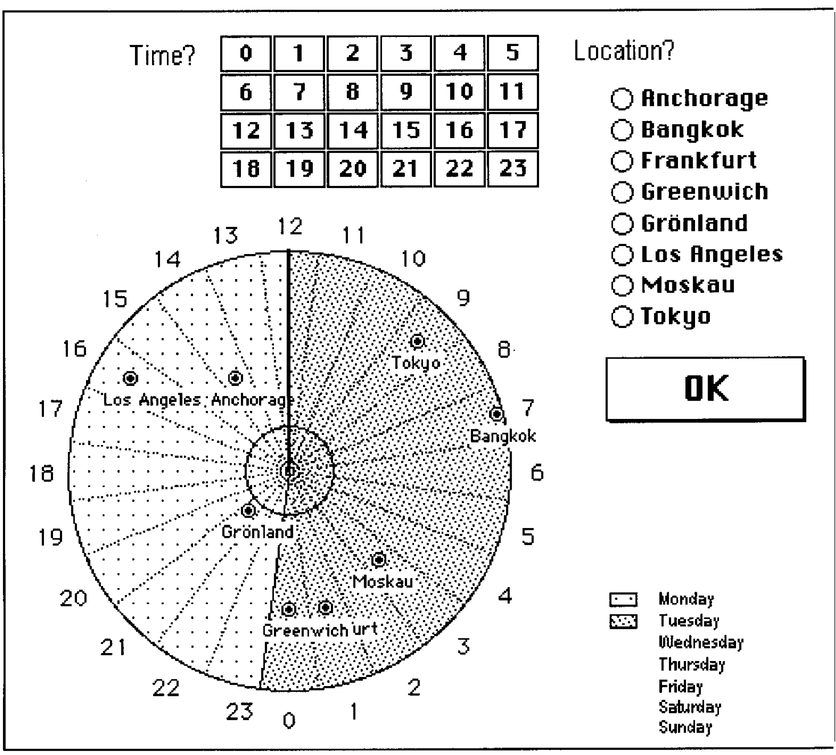
One of the frequently used features in computer-based multimedia learning environments is animation. Any element on a computer screen can be animated, but the most frequent use of animation concerns animated pictures. Animated pictures can be used to support 3-D perception by showing an object from varying perspectives. They can be used to direct the observer's attention to important (and unimportant) aspects of a display, convey procedural knowledge (e.g., in software training), demonstrate the dynamics of a subject matter, and allow exploratory learning through manipulating a displayed object. Furthermore, they can have a supplantative effect (Salomon, 1994), when they help learners to perform a cognitive process that they could not otherwise perform without this external support. Despite a widespread belief that animation is a powerful instructional device, however, it is still an open question under which conditions animated pictures really enhance comprehension and learning (Tversky, Morrison, & Betrancourt, 2002).

FUNCTIONS OF ANIMATIONS

Animations can have two basic functions based on a reduction of cognitive load. (a) If they reduce the cognitive load of tasks in order to allow cognitive processing that would otherwise be impossible, then animations have an *enabling function.* (b) If they reduce the cognitive load of tasks that could otherwise be solved only with high mental effort, then animations have a *facilitating function* (cf. Mayer, 2001; Sweller & Chandler, 1994; Sweller, van Merriënboer, & Paas, 1998). For example, when students learn about time phenomena related to the earth's rotation, animated pictures like those in Figures 1 and 2 can be useful. In these figures, the earth is depicted as a sphere viewed from the North Pole that rotates in a space where different locations are associated with different states of time. The picture shown in Figure 1 can be manipulated by the learner, who can define specific days or times for specific cities. After the learner clicks on the OK button, the earth moves into the corresponding time state. We will call this a manipulation picture. Because a manipulation picture enables learners to investigate a high number of different time states, which would not be possible on the basis of a static picture, such a picture is assumed to have an enabling function.

The picture shown in Figure 2 can be used to simulate the earth's rotation. The learner can choose different ways that a traveler can circumnavigate around the earth (symbolized by a black dot moving in a western or eastern direction, with different traveling speed depending on the learner's choice). After the learner presses the SIMULATION button, the earth starts rotating and the traveler's dot starts moving on the rotating earth. We will call this a simulation picture. It might be much easier for students to observe the rotation of the earth and the movement of an object in a simulation picture than to perform the corresponding mental simulations on their own with only a static picture (Lowe, 1999; Sims & Hegarty, 1997). Thus, such a picture is assumed to have a facilitation function. The

Figure 1 ☐ Example of a manipulation picture.



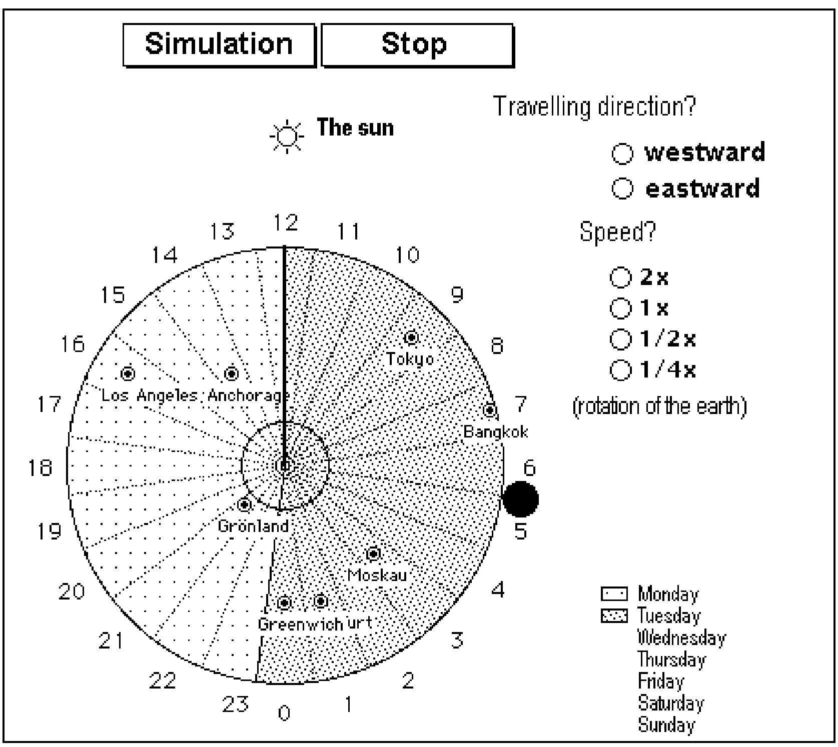
study was aimed at analyzing how the assumed functions of animations affect cognitive processing and learning results.

STUDY 1

This study focused on a comparison between learning from animated (manipulation and simulation) pictures and learning from static pictures. If animated pictures *enable* the learner to perform additional cognitive processing, the learner's total amount of processing should increase. Because additional processing needs additional time, the enabling function of animations should lead to an increase of learning time compared to corresponding static pictures. The enabling function is expected to be more pronounced when individuals have high learning prerequisites (high cognitive ability and high prior knowledge) because these learners will be able to use the possibilities of animations more extensively than individuals with low learning prerequisites. If animated pictures *facilitate* cognitive processing, the learner needs less effort with animated pictures than with static ones, because the animation reduces cognitive load to a degree that is easier to cope with. Thus, if the facilitating function of animations applies, learners will invest less learning time into animated pictures than into corresponding static pictures. The facilitating function is expected to be more pronounced when learners have low prerequisites because these individuals need more external support than learners with high prerequisites.

If animated pictures enable individuals with high learning prerequisites to do additional cognitive processing, these learners will spend more time observing animated pictures than static pictures. If animated pictures facilitate processing for individuals with low learning prerequisites, these learners will spend less time observing animated pictures than static pictures. Following this line of reasoning it seems plausible to assume that there is an interaction between

Figure 2 ☐ Example of a simulation picture.



learning prerequisites (high-low) and type of pictures (animated-static) on learning time. This leads to the following hypothesis:

(H1) Students with high learning prerequisites will spend more time studying animated pictures than static pictures, whereas students with low learning prerequisites will spend less time studying animated pictures than static pictures.

If animated pictures enable learners with high prerequisites to do more cognitive processing, this additional processing should also lead to better learning. Thus, one can assume the following hypothesis regarding the enabling function of animated pictures for students with high learning prerequisites:

(H2a) Students with high learning prerequisites learn more from animated pictures than from static pictures.

If animated pictures facilitate cognitive processing for learners with low prerequisites and allow them to process information more successfully, this should also lead to better learning. Thus, one can assume the following hypothesis regarding the facilitating function of animated pictures for students with low learning prerequisites:

(H2b) Students with low learning prerequisites learn more from animated pictures than from static pictures.

The two hypotheses, H2a and H2b, could be integrated into an overall hypothesis that assumes, that independent of individual learning prerequisites, students learn more from animated pictures than from static pictures. It should be noted, however, that there are different reasons behind this overall prediction.

Method

Learners and learning material. Participants were 40 university students randomly assigned to 2 groups of 20. Learning material was a computer-based hypertext that consisted of 22 cards (paragraphs) with 2,750 words about time and date differences on the earth, and about the results of circumnavigations around the earth. One group received the text with animated pictures and the other group with static pictures. The pictures showed the earth as a sphere rotating in a space in which different locations were associated with different time states. In the animation group, 5 pictures allowed manipulations by defining specific days or times for specific geographical locations, as shown in Figure 1, and 5 pictures allowed choice among different ways of circumnavigating around the earth with a visual simulation of the earth's rotation and a visualization of different circumnavigation, as shown in Figure 2. The static pictures were identical but did not include buttons for manipulation or simulation. In both groups, the learners had free access to the text paragraphs and pictures via a hierarchically organised menu.

Procedure and scoring. In the pretest phase, participants were given a paper-and-pencil test for prior knowledge, in which they had to explain a series of concepts referring to time phenomena on the earth, and an intelligence test (Intelligenz-Struktur-Test 70 of Amthauer, 1973). They were given prior knowledge scores on the basis of their written protocols, and intelligence scores based on their test results. In the subsequent practice phase, learners made themselves familiar with the hypertext system, referring to other subject matter unrelated to that used in the experiment. The practice phase served to avoid any extraneous cognitive load caused by an unfamiliar learning environment. In the following learning phase, all students received the hypertext about time phenomena on the earth with either animated pictures or static pictures. In order to provide an orientation for learning, participants received a sequence of 10 questions. Of the questions, 5 were related to time differences between different places on the earth, and the remaining questions addressed time and date changes related to circumnavigations of the earth.

Participants had free access to the available text and picture information. They could take notes on a sheet of paper, and they had unlimited learning time. The students were informed that they would subsequently be tested for their comprehension with similar questions but without further access to the learning material. In order to avoid a too strong task-oriented limitation of their exploratory activities, participants did not receive feedback on whether their answers were correct or incorrect. Picture observation times were automatically recorded for each learner by the hypertext system.

In the final posttest phase, participants were required to apply the acquired knowledge in a comprehension test without further access to the learning material or their notes. The test consisted of 24 multiple-choice items, and there was no time limit imposed for answering; 12 items referred to time differences between different places on the earth (e.g., "What is the time in Anchorage, if it is Thursday 9 o'clock p.m. in Tokyo?"). These questions required knowledge about the subdivision of the earth's surface into time zones, and about the time coordinates of different cities and are referred to as time-difference questions. The remaining 12 items dealt with time phenomena related to circumnavigations of the world (e.g., "Why did Magellan's companions think, upon their arrival after sailing around the world, that it was Wednesday when it was actually already Thursday?") These questions required participants to perform internal simulations based on a mental model of the earth including time zones and the date line, as well as date zones, and are referred to as circumnavigation questions. For each participant, the number of correctly answered time-difference questions was determined as his or her time-difference score, and the number of correctly answered circumnavigation questions as the circumnavigation score.

Results

In order to differentiate between participants with high and low learning prerequisites, regression analyses were performed, with prior knowledge and intelligence as predictors, and learning results (sum of correctly answered time-difference questions and sum of correctly answered circumnavigation questions) as the dependent variables. The resulting linear combination of prior knowledge and intelligence served for determining the individual value of learning prerequisites for each participant. Subsequently, the sample was divided through a median split into a group of 20 learners with high learning prerequisites and a group of 20 learners with low learning prerequisites. The means and standard deviations of the picture observation times, of the time-difference scores, and of the circumnavigation scores of learners with static pictures and of learners with animated pictures are presented in Table 1, which further differentiates between high and low learning prerequisites.

A 2 × 2 analysis of variance (ANOVA) (Picture Type × Learning Prerequisites) of the picture observation times yielded neither a significant main effect of picture type ($F(1, 36) = 0.195$, n.s.) nor a significant main effect of learning prerequisites ($F(1, 36) = 1.627$, n.s.), but a significant interaction Picture Type × Learning Prerequisites ($F(1,36) = 3.171$, $MSE = 1453.313$, $p = .042$, $\eta^2 = .081$). When students had high learning prerequisites, they spent more time on animated pictures than on static pictures, which was marginally significant ($t(18) = 1.306$, $p = .104$, $d = 0.58$). When students had low learning prerequisites, they spent less time on animated pictures than on static pictures, which was also marginally significant ($t(18) = 1.294$, $p = .106$, $d = 0.58$). Although the observed a priori contrasts failed to become significant, the significant interaction Picture Type x Learning Prerequisites can be considered as preliminary support of Hypothesis H1, which implies that students with high learning prerequisites are more likely to spend more time studying animated pictures than static pictures compared to students with low learning prerequisites, who are more likely to spend more time studying static pictures than animated pictures. The results correspond to the assumption that the enabling function of animations applies to students with higher learning prerequisites, whereas the facilitating function applies to students with lower learning prerequisites.

A corresponding 2 × 2 ANOVA of the time-difference scores showed a significant effect of learning prerequisites ($F(1, 36) = 5.528$, $MSE = 7.603$, $p = .012$, $\eta^2 = .133$) and a highly significant effect of picture type ($F(1, 36) = 8.553$, $MSE = 7.603$, $p = .003$, $\eta^2 = .192$). The interaction Picture Type × Learning Prerequisites was not significant ($F(1, 36) = 0.082$, n.s.). Students with high learning prerequisites outperformed students with low learning prerequisites, and students with animated pictures outperformed students with static pictures in answering time-difference questions. Students with high learning prerequisites performed significantly better in answering time-difference questions after learning from animated pictures than after learning from static pictures ($t(18) = 2.316$, $p = .017$, $d = 1.04$), which corresponds to Hypothesis H2a. Students with low learning prerequisites also answered these questions significantly better after learning from animated pictures rather than static ones ($t(18) = 1.830$, $p = .042$, $d = 0.82$), which corresponds to Hypothesis H2b.

Contrary to the analysis of time-difference scores, the corresponding 2 × 2 ANOVA of the circumnavigation scores showed neither a significant effect of picture type ($F(1, 36) = 2.380$, $MSE = 6.564$, n.s.) nor a significant effect of learning prerequisites ($F(1, 36) = 0.187$, n.s.), and no significant interaction Picture Type × Learning Prerequisites ($F(1, 36) = 2.380$, n.s.). With regard to Hypothesis H2a, students with high learning prerequisites answered circumnavigation questions equally well after learning with animated pictures and after learning with static pictures ($t(18) = 0.0$, n.s.). With regard to Hypothesis H2b, surprisingly, students with low learning prerequisites answered circumnavigation questions better after learning with static pictures than after animated ones ($t(13.5) = 2.380$, $p = .033$, $d = 1.07$). In other words, Hypothesis H2a did not receive any support from the circumnavigation questions. There was also no evidence for Hypothesis H2b, but rather for the opposite prediction: Animated pictures did not have positive effects on answering these questions, but were harmful when students had lower learning prerequisites.

Discussion

It was assumed that animations can have both an enabling and a facilitating function in the process of learning. The picture observation times indicate that the individual's learning prerequisites decide which function dominates. For individuals with high prerequisites, animations seem to have an enabling rather than a facilitating function. For individuals with low learning

Table 1 ☐ Means and standard deviations of picture observation times and learning results in Study 1

	Mean			Standard Deviation			Sample Size	
Learning prerequisites	*Static Pictures*	*Animated Pictures*	*Total*	*Static Pictures*	*Animated Pictures*	*Total*	*Static Pictures*	*Animated Pictures*
Picture Observation Times (seconds)								
Whole sample	1728	1559	1643	1638	661	1236	20	20
Low	2310	1463	1887	1998	542	1489	10	10
High	1145	1656	1400	960	780	891	10	10
Learning Results: Time Difference Questions								
Whole sample	4.10	6.65	5.38	2.38	3.31	3.13	20	20
Low	3.20	5.50	4.35	2.20	3.31	2.98	10	10
High	5.00	7.80	6.40	2.31	3.05	3.00	10	10
Learning Results: Circumnavigation Questions								
Whole sample	8.95	7.70	8.33	2.86	2.27	2.63	20	20
Low	9.40	6.90	8.15	2.95	1.52	2.62	10	10
High	8.50	8.50	8.50	2.84	2.68	2.69	10	10

prerequisites, animations seem to have a facilitating rather than an enabling function. The findings concerning answering time-difference questions supported the assumption that animations result in better learning because of their enabling or facilitating function. The findings concerning answering circumnavigation questions, however, did not give any evidence for this assumption: Learners with high learning prerequisites did not profit from the animations, and learners with low learning prerequisites, surprisingly, performed even better with static pictures than with animated pictures.

In order to understand this unexpected divergence between time-difference and circumnavigation scores, it may be helpful to analyse the cognitive processes required by the corresponding questions more closely. Answering time-difference questions requires knowledge about time coordinates of various cities in the world, and the time differences between them. Manipulation pictures such as that shown in Figure 1 can be used to display a high number of different time states, which should be a good basis to extract information about time differences. Thus, the high performance of the animation group in answering time-difference questions might correspond to the enabling function of such animations.

Answering circumnavigation questions requires mental simulations. Simulation pictures such as that in Figure 2 provide external support for such simulations. It may well be possible that under specific conditions this function will be beneficial for learning, namely if individuals have abilities too low to perform mental simulations on their own (Salomon, 1994; Sweller & Chandler, 1994; van Gog, Ericsson, Rikers & Paas, 2005). Our study indicates, however, that facilitation can also have a negative effect on learning. If individuals are capable of performing such mental simulations by themselves, then external support can make processing unnecessarily easy and, thus, students invest less cognitive effort in learning from animation than in learning from static pictures. From the perspective of cognitive load theory, animation can unnecessarily reduce germane load associated with deeper meaningful cognitive processing (Sweller, 1999; Sweller et al., 1998; van Merriënboer, 1997). Most learners had obviously sufficient skills for mental simulations without external support, but students with lower cognitive prerequisites were apt to accept unneeded external support.

This negative effect of the facilitating function of animations has similarities with the effects of redundancy in cognitive load theory. Sometimes, information from one source is self-contained, when it provides all the required information for knowledge construction. If the same information is provided again in a different form, this creates redundancy. Such redundancy usually increases cognitive load instead of reducing it, because processing of the unneeded information means a waste of cognitive capacity (Kalyuga, Chandler, & Sweller, 1998). However, whereas the redundancy effect is explained by an increase of extraneous cognitive load due to the processing of additional (unneeded) information, which reduces the remaining mental capacity, the assumed negative effect of the facilitating function of animation is interpreted as a result of an (unintended) decrease of germane cognitive load, because available mental capacity is left unused for the process of learning.

Furthermore, our study indicates that animations can have different effects on different tasks. As the manipulation pictures seem to allow deeper analysis of time differences, their enabling function results in better performance with time-difference questions. Simulation pictures seem to make mental simulations easier, but this facilitating function can be harmful for learning, when individuals who were able to perform these mental simulations on their own are indirectly hindered in doing so by unnecessary external support. In this case, animation has an inhibiting effect on learning because of an inadequate reduction of germane cognitive load. The simulation pictures stimulate behavioral interactivity, but do not stimulate mental activity—a result that corresponds to the findings of Moreno and Valdez (2005).

Because the animation treatment in Study 1 included manipulation pictures as well as simulation pictures, it was not possible to distinguish between different effects of different kinds of animation. We assumed that manipulation pictures have primarily an enabling function, which is especially important for time-difference questions, whereas simulation pictures have primarily a facilitating function, which is especially important for circumnavigation questions. In order to analyse in more detail whether the different kinds of animation have different cognitive functions for different kinds of learners, a second study was conducted.

STUDY 2

Study 2 compared different kinds of animation: manipulation pictures and simulation pictures. The manipulation pictures allowed a high number of different time states to be generated for explorative purposes, as shown in Figure 1. The simulation pictures allowed continuous external simulation of the earth's rotation, with a fixed rotation speed of 4.8 rpm that could not be controlled by the learner, combined with a circumnavigation around the earth at different speeds, as shown in Figure 2. We assumed that the manipulation pictures have an enabling function that is especially helpful for answering time-difference questions, and which is more pronounced (according to Study 1) if learners have high rather than low learning prerequisites. The following hypothesis for students with high learning prerequisites was posited:

(H3a) Manipulation pictures lead to better performance in answering time-difference questions than simulation pictures, if learners have high learning prerequisites.

We further predicted an interaction between picture type and learning prerequisites according to the following hypothesis:

(H3b) Manipulation pictures are more beneficial for answering time-difference questions (compared to simulation pictures) for learners with high learning prerequisites than for learners with low learning prerequisites.

Furthermore, we assumed that the simulation pictures have a facilitating function that affects primarily circumnavigation questions, and which is more pronounced if learners have low rather than high learning prerequisites. In Study 1, we found that this facilitating function had negative effects on learning, because the external support had made processing unnecessarily easy for our students. We therefore expected that simulation pictures would result in lower performance with circumnavigation questions than manipulation pictures, and that this effect would be more pronounced when students have low rather than high learning prerequisites. The following hypothesis was therefore derived for students with low learning prerequisites:

(H4a) Simulation pictures lead to lower performance in answering circumnavigation questions than manipulation pictures, if learners have low learning prerequisites.

We furthermore predicted an interaction between picture type and learning prerequisites according to the following hypothesis:

(H4b) Simulation pictures are more harmful for answering circumnavigation questions (compared to manipulation pictures) for learners with low learning prerequisites than for learners with high learning prerequisites.

Method

Participants of Study 2 were 26 university students who were randomly assigned to two groups; 13 students to the manipulation group, and 13 to the simulation group. The learning material was the same as in Study 1, except that the manipulation group received a text that included only five manipulation pictures, and the simulation group received a text that included only five simulation pictures. The procedure of Study 2 was exactly the same as in Study 1. In the final posttest phase, participants were again asked to apply the acquired knowledge in a comprehension test without further access to the learning material or to notes. The test included 12 time-difference questions and 12 circumnavigation questions. For each participant, the number of correctly answered time-difference questions and the number of correctly answered circumnavigation questions were determined.

Results

In order to differentiate between participants with high and low learning prerequisites, regression analyses were performed, with prior knowledge and intelligence as predictors and learning results (sum of correctly answered time-difference questions and sum of correctly answered circumnavigation questions) as the dependent variables. Based on the resulting linear combination of prior knowledge and intelligence, participants were assigned through a median split to a group of 14 learners with high learning prerequisites, and a group of 12 learners with low learning prerequisites. Table 2 shows the means and standard deviations of the time-difference scores and the circumnavigation scores of the manipulation group and the simulation group. It further differentiates between high and low learning prerequisites.

A 2 × 2 ANOVA of the time-difference scores with the factors animation type and learning prerequisites showed a marginally significant effect of animation type ($F(1, 22) = 1.743$, $MSE = 2.501$, $p = .10$), a highly significant effect of learning prerequisites ($F(1, 22) = 10.211$, $p = .002$, $\eta^2 = .317$) and a significant interaction Animation Type × Learning Prerequisites ($F(1, 22) = 4.511$, $p = .023$, $\eta^2 = .170$). Students with manipulation pictures outperformed students with simulation pictures, and students with high learning prerequisites performed better than students with low learning prerequisites. When learners had high learning prerequisites, they had significantly higher time-difference scores after learning from manipulation pictures than after learning from simulation pictures ($t(12) = 2.287$, $p = .021$, $d = 1.22$), whereas learners with low learning prerequisites had lower scores with manipulation pictures than with simulation pictures. Thus, the results support Hypotheses H3a and H3b. Accordingly, manipulation pictures have an enabling function that is helpful for answering time-difference questions, but only if learners have sufficiently high learning prerequisites.

A 2 × 2 ANOVA of the circumnavigation scores with the factors animation type and learning prerequisites yielded a significant effect of animation type ($F(1, 22) = 5.020$, $MSE = 2.896$, $p = .018$, $\eta^2 = .186$), and a significant effect of learning prerequisites ($F(1, 22) = 4.109$, $p = .028$, $\eta^2 = .157$), but no significant interaction Animation Type × Learning Prerequisites ($F(1, 22) = 0.558$, n.s.). Learners with simulation pictures showed lower performance than learners with manipulation pictures, and students with high learning prerequisites outperformed students with low learning prerequisites. Because of the nonsignificant interaction Animation Type × Learning Prerequisites, there was no support for Hypothesis H4a. However, students with low learning

Table 2 ☐ Means and standard deviations of learning results in Study 2

	Mean			*Standard Deviation*			*Sample Size*	
Learning prerequisites	*Manipulation Pictures*	*Simulation Pictures*	*Total*	*Manipulation Pictures*	*Simulation Pictures*	*Total*	*Manipulation Pictures*	*Simulation Pictures*
Learning Results: Time Difference Questions								
Whole sample	3.62	2.69	3.15	2.06	1.84	1.97	13	13
Low	1.83	2.33	2.08	1.17	1.51	1.31	6	6
High	5.14	3.00	4.07	1.21	2.16	2 .02	7	7
Learning Results: Circumnavigation Questions								
Whole sample	5.46	4.00	4.73	1.90	1.68	1.91	13	13
Low	5.00	3.00	4.00	1.41	0.89	1.54	6	6
High	5.86	4.86	5.36	2.27	1.77	2.02	7	7

prerequisites had lower performance in answering circumnavigation questions after learning from simulation pictures than after learning from manipulation pictures ($t(10) = 2.928$, $p = .008$, $d = 1.70$). This corresponds to Hypothesis H4b, which assumed that simulation pictures result in lower performance with circumnavigation questions than manipulation pictures, especially if learners have low learning prerequisites. Thus, simulation pictures seem to have a facilitating function, especially for students with low learning prerequisites, which affect the answering of circumnavigation questions. However, this function turned out again to be harmful for these learners, because the external support had made processing unnecessarily easy.

Discussion

The findings should be interpreted with caution because of the relatively small number of participants. The results indicate that the different kinds of animations have, indeed, different functions in the process of learning. Whereas the manipulation pictures seem to have primarily an enabling function, the simulation pictures seem to have primarily a facilitating function. Manipulation pictures seem to be primarily beneficial for answering time-difference questions. Learners can use such pictures to generate various time states of the earth in order to extract information about time differences, which was obviously helpful later for answering time-difference questions. This function seems to be especially pronounced when students have higher learning prerequisites, because these learners have sufficient resources available to use these possibilities (cf., Clarke, Ayres, & Sweller, 2005). Simulation pictures seem to affect primarily the answering of circumnavigation questions. They have a facilitating function insofar as they allow following an external simulation process that makes the corresponding mental simulation much less demanding. This function might be beneficial for learners who would not be able to perform this mental simulation at all without external support (cf., Mayer, 1997, 2001; Salomon, 1994; Schnotz, Boeckheler, & Grzondziel, 1999). However, if learners are able to perform the mental simulation on their own, the external support prevents them from performing learning-relevant cognitive processes on their own. In this case, the facilitating function is beneficial for processing, but not for learning.

GENERAL DISCUSSION

Compared to static pictures, animated pictures provide additional information that seems to have different functions for learning. On the one hand, animations can enlarge the set of possible cognitive processes and, thus, allow learners to perform more processing than they would be able to perform with static pictures. This is the enabling function of animations. On the other hand, animations can trigger dynamic cognitive schemas that make specific cognitive processes easier. This is the facilitating function of animations.

Different kinds of animated pictures seem to fulfil different functions for learning. Manipulation pictures that allow the learner to generate and display a large number of static pictures, showing different states or showing a subject matter from different perspectives, seem to have primarily an enabling function. They enable learners to perform more cognitive processing than they would be able to do with static pictures. Simulation pictures, on the other hand, which allow displaying dynamic processes, seem to have primarily a facilitating function. They provide external support for corresponding mental simulations and, thus, make these mental processes easier to perform. Individuals with high learning prerequisites seem to benefit primarily from the enabling function, whereas individuals with low learning prerequisites seem to be affected primarily by the facilitating function of animations.

Both the enabling function and the facilitating function of animation can be considered as a reduction of cognitive load (Sweller et al., 1998). The facilitating function of animations can be helpful for learners with very low ability or prior knowledge who would not be able at all to perform the corresponding mental simulations without external support (cf., Wallen, Plass, &

Brünken, 2005). The two studies presented above, however, have shown that the facilitating function of animations can also be harmful, particularly if learners who could perform the mental simulations on their own, nevertheless made use of the unneeded external support. Animation can keep learners from doing relevant cognitive processing, not because of increased task difficulty, but because of an inappropriate facilitation of the task. In this case, the animation reduces cognitive load, but unfortunately it also reduces germane load that is necessary for learning instead of the extraneous load. The use of animation in multimedia learning environments seems to be beneficial only under some circumstances, whereas it can have negative effects under other circumstances.

When generalizing these results, one should keep in mind, however, that the distinction between high and low learning prerequisites is always relative. Only those learners who *try* to perform their own mental simulations can be hindered by unneeded help or suffer from interference with the external animation. Learners with low cognitive abilities may not even try to perform a mental simulation without external support by an animation. If no learning occurs from such mental simulations with static pictures or manipulation pictures, then simulation pictures cannot be harmful, simply because there cannot be less learning than no learning.

As animation provides additional and transient information, one could also argue that animation does not decrease, but rather increases cognitive load as an effect of redundancy. It is well known that presenting redundant information can be considered as an increase of extraneous cognitive load, because learners have to process additional, but unneeded information. Such redundancy can result in an expertise reversal effect, when individuals with higher learning prerequisites perform better without, rather than with, additional information (Kalyuga et al., 1998; Kalyuga & Sweller, 2005).

In the studies presented above, the negative effects of animation derived from the facilitating function were found primarily when students had low learning prerequisites rather than high learning prerequisites. Consequently, this pattern of results is not consistent with an expertise reversal effect Nevertheless, it is a weakness of the studies that they did not directly measure cognitive load by a rating scale (Paas & van Merriënboer, 1994), but used cognitive load theory only as an interpretative framework. A direct measure of cognitive load in further studies could help to decide whether the negative effects of animation can be attributed to an increase of extraneous cognitive load due to redundancy or to an unintended decrease of germane cognitive load due to an inappropriate facilitation of the task. An important aspect that has been ignored in this study is how a learner's willingness to invest mental effort into a learning task is affected by the cognitive load associated with the task (cf., Paas, Tuovinen, van Merriënboer, & Darabi, 2005). Another topic of interest would be the different roles played by prior knowledge (which could be considered as the learner's inventory of cognitive schemas) and intelligence (which could be considered as the quality of cognitive processing based on these schemas) in learning from animation. Further research will be required to clarify these questions. □

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