Enabling, Facilitating, and Inhibiting Effects in Learning from Animated Pictures

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Abstract: Animated pictures can have different functions in the process of learning. They can have an enabling function if they allow the learner to perform a higher amount of cognitive processing than static pictures. They can also have a facilitating function if they make specific cognitive processes easier to perform through external support. Two experiments were carried out which investigated differences between learning from animated and learning from static pictures and which analysed whether different kinds of animation have different cognitive functions for different kinds of learners. Results indicate that manipulation pictures have primarily an enabling function for learners with higher prior knowledge, whereas simulation pictures have primarily a facilitating function for learners with lower prior knowledge. This facilitating function is not necessarily beneficial, because unneeded external support can hinder learners to perform relevant cognitive processes.

Introduction

Computer-based multimedia learning environments can flexibly display various kinds of representations (Peterson, 1996). They frequently present animated pictures, which can be manipulated for active exploratory learning and which allow to display the dynamic behavior of complex subject matters. Pictures can be considered to be animated if their graphical structures changes during presentation. Animated pictures serve different purposes: They can be used to support the 3D perception of a 2D display by rotating the 3D object or to direct the observers attention to important (and unimportant) aspects of a display. They can support the acquisition of procedural knowledge as, for example, in the area of software training, when the steps of an interaction with a computer are modelled on the display by animated pictures. Animations can elaborate instructions with process information by presenting the dynamic aspects of a subject matter which cannot be displayed by a static picture. Furthermore, animations can have a so-called supplantation function. That is, they can help a learner to perform cognitive processes, which he/she would not yet be able to perform without this external support (Salomon, 1994).

Practitioners in the field of instructional design often take it as only natural that a dynamic subject matter should be presented by animated pictures. If, for example, subjects are expected to learn why there exist simultaneously different daytimes and different days on the earth, learners could be presented animated pictures like those shown in figure 1 and figure 2. In these figures, the earth is depicted as a sphere viewed from the north pole which rotates in a shell of different time states. With figure 1, learners can manipulate the picture by defining specific daytimes for specific cities in order to create the corresponding time state on the earth by pressing the OK-button. In figure 2, learners can simulate the earth's rotation and choose among different ways of a traveller's circumnavigating around the earth (symbolized in figure 2 by a black dot).

Animated pictures provide one the one hand additional information and, thus, enable more cognitive processing than static pictures. With pictures like that in figure 1 learners can, for example, explore the subject matter by manipulating the picture which would not be possible with static pictures. This possibility of additional cognitive processing due to information enrichment is in the following called the *enabling function* of animations. On the other hand, animated pictures can give external support for mental simulations and, thus, facilitate cognitive processing. With pictures like that in figure 2 learners can, for example, observe the rotation of the earth or the movement of an object travelling around the earth with different speed, which is much easier than performing the corresponding mental simulations only on the basis of a static picture (Forbus, Nielsen & Faltings, 1991; Lowe, 1999; Sims & Hegarty, 1997). This possibility of making cognitive processing easier is

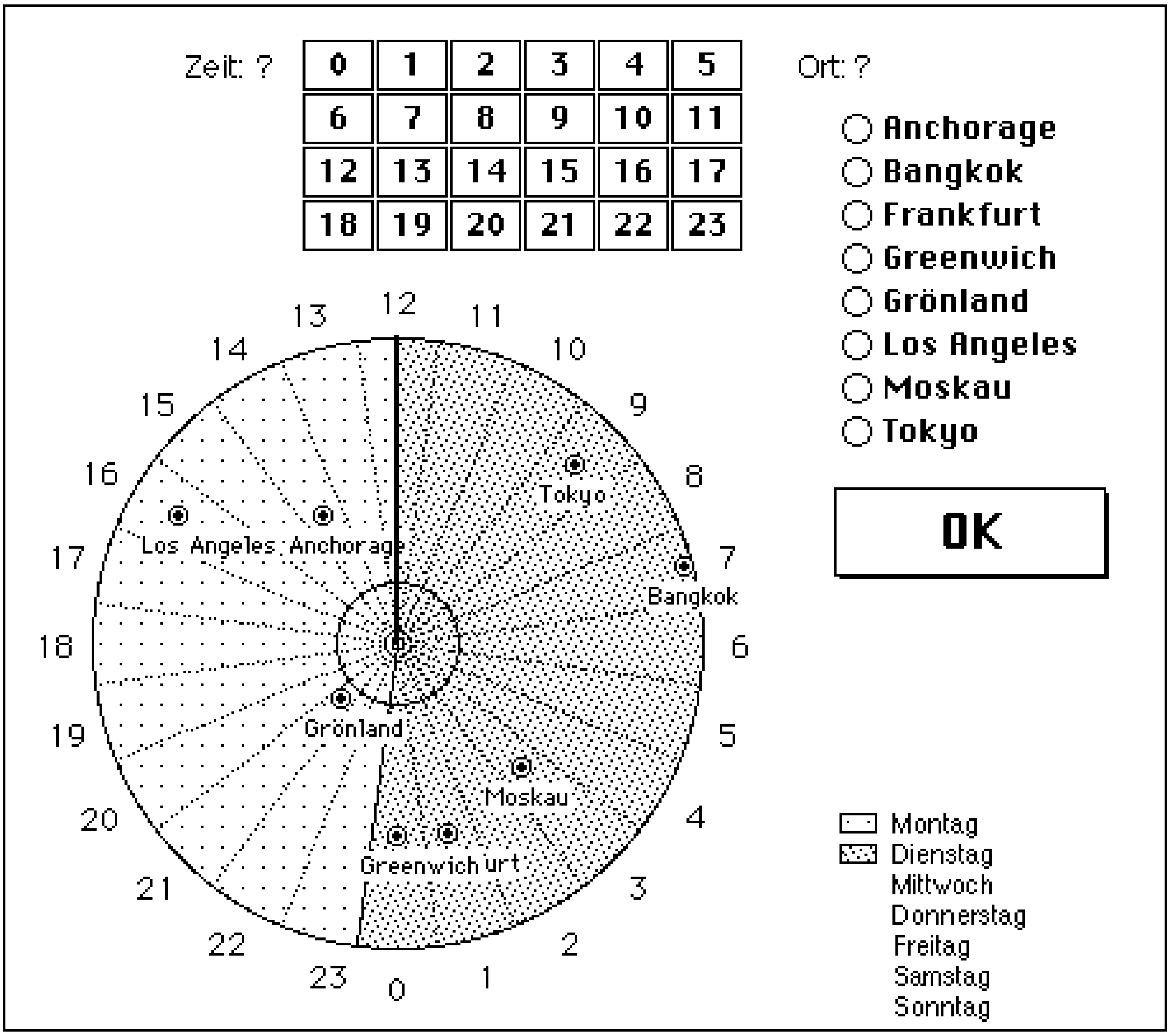

Fig. 1: Example of a manipulation picture that can be used to explore the depicted subject matter. The picture shows the earth with time zones seen from the Northpole. Learners can select different daytimes for different cities and turn the earth in the corresponding position.

called here the *facilitating function* of animations. The following paper presents two empirical studies which aimed at answering the question, which effects of animations can be expected under which conditions in the process of learning according to their enabling and the facilitating function.

STUDY 1

Theoretical Assumptions

Study 1 aimed at analyzing differences between learning from animated pictures and learning from static pictures for different kinds of learners. On the one hand, one can assume that the enabling function of animations is bound to specific cognitive prerequisites like the learner's prior knowledge. Accordingly, the enabling function of animations should be more dominant if learners have high prior knowledge than if they have low prior knowledge. On the other hand, one can accume that the facilitating function of animations plays a more important role if learners have low prior knowledge, because these learners still need external support for their cognitive processing, than if they have high prior knowledge. Thus, one can deduce the following hypotheses regarding the cognitive demands as well as the results of learning from animated and learning from static pictures.

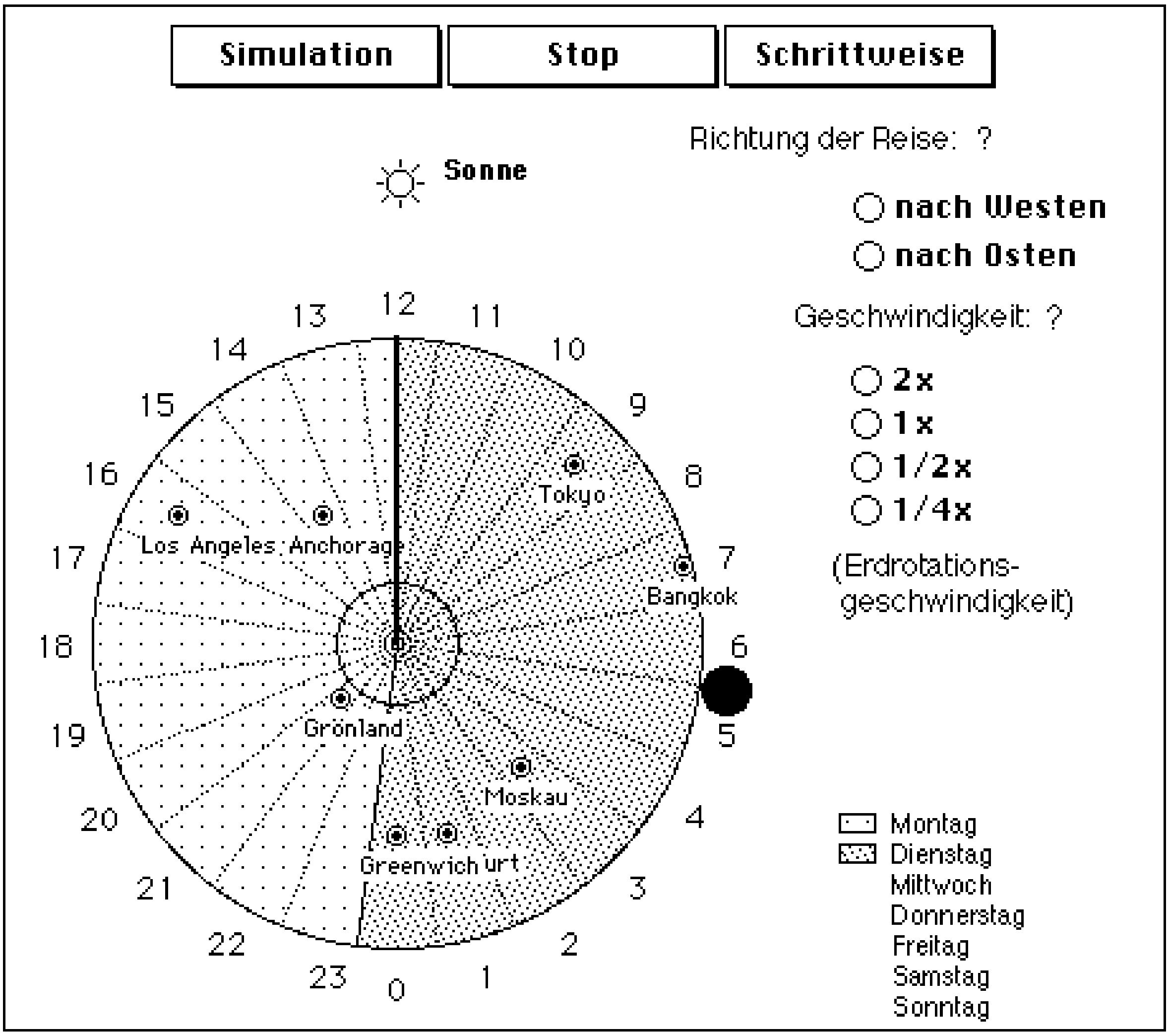

Fig. 2: Example of a simulation picture that can be used as external support for mental simulations. The picture shows the earth with time zones seen from the Northpole. Learners can select among different kinds of circumnavigations around the world and observe the Earth's rotation as well as the results of the circumnavigation in a continuous or a stepwise mode.

Enabling Function. If animated pictures present additional information and, thus, enable the learner to perform more cognitive processing than static pictures, then the learner's amount of cognitive becomes higher, because the learner performs cognitive processes that he/she would not have performed with static pictures. Such additional cognitive processing needs additional time. Thus, if the enabling function of animations applies specifically to learners with high prior knowledge, then one can deduce as hypothesis E1 that these learners will invest more learning time into animated pictures than into static pictures:

(E1) HIGH PRIOR KNOWLEDGE: PICTURE TIME ANIM > PICTURE TIME STAT

As the additional cognitive processing should also lead better learning, one can deduce as hypothesis E2 that learners with high prior knowledge will have better learning results with animations than with static pictures:

(E2) HIGH PRIOR KNOWLEDGE: LEARNING RESULT ANIM > LEARNING RESULT STAT

Facilitating Function. If animated pictures provide external support for specific cognitive processing according to their facilitating function, then the learner needs less effort to perform these processes than he/she would need with static pictures. Accordingly, an animation can reduce cognitive load to a degree that can still be handled by the learner (Mayer, Moreno, Boire & Vagge, 1999; Sweller & Chandler, 1994; van Merrienboer, 1997). Thus, if the facilitating function of animations applies specifically to learners with low prior knowledge, then one can deduce as hypothesis F1 that these learners will invest less learning time into animated than into static pictures:

(F1) LOW PRIOR KNOWLEDGE: PICTURE TIME ANIM < PICTURE TIME STAT

If learners with low prior knowledge can perform cognitive processes based on an animation due to its facilitating function which they could not do with static pictures, then one can deduce as hypothesis F2 that these learners perform more cognitive processing and thus have better learning results with animations than they would have with static pictures.

(F2) LOW PRIOR KNOWLEDGE: LEARNING RESULT ANIM > LEARNING RESULT STAT

Method

Subjects and Learning Material. 40 university students participated in study 1 who were randomly assigned to 2 groups of 20 subjects. Learning material was a computer-based hypertext which consisted of 22 cards (paragraphs) with 2750 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 shell of different time states. They allowed manipulations by defining specific daytimes for specific locations as shown in figure 1, or they allowed to choose 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 subjects had free access to the text paragraphs and pictures via an hierarchically organised menu.

Procedure and Scoring. In the pretest phase, subjects were given a paper and pencil test of prior knowledge in which they had to explain a series of concepts referring to time phenomena on the earth. Subjects were given prior knowledge scores on the basis of their written protocols. Based on the prior knowledge scores, subjects were assigned through to a median split to a high and a low prior knowledge group. In the subsequent practice phase, subjects made themselves familiar with the hypertext system referring to another subject matter (unrelated to that used in the experiment). In the following learning phase, all subjects received the hypertext about time phenomena on the earth with either animated pictures or static pictures. In order to provide an orientation for learning, subjects received a sequence of 10 questions. 5 of these questions were related to time differences between different places on the earth while the remainder addressed time and date changes related to circumnavigations of the earth. Subjects had unlimited learning time. They had free access to the available text and picture information and they could take notes on a sheet of paper. They 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, subjects did not receive feedback whether their answers were correct or incorrect. Reading times and picture observation times were automatically recorded for each subject by the hypertext system.

In the final posttest phase, subjects 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 Tokio?*). These questions required knowledge about the subdivision of the earth's surface into time zones and about the time co-ordinates of different cities and are referred to as time difference questions. 12 items dealt with time phenomena related to circumnavigations of the world (e.g. *Why did Maghellan's companions think, upon their arrival after sailing around the world, that it was Wednesday when it was actually already Thursday?*) These questions required to perform internal simulations based on a mental model of the earth indluding time zones, the date line as well as date zones, and are referred to as circumnavigation questions. The number of correctly answered time difference questions and the number of correctly answered circumnavigation questions was determined for each subject.

Results

Picture Observation Times. Subjects with higher prior knowledge had slightly higher picture observation times with animations (M=1580sec; SD=768sec) than with static pictures (M=1425sec; SD=1142). This result corresponds to hypothesis E1, but the difference does not reach significance. Subjects with lower prior knowledge had lower picture observation times with animations (M=1538sec; SD=576sec) than with static pictures (M=2181sec; SD=2200). This result is in line with hypothesis F1, but due to the high variances the difference does also not reach significance.

Learning Results: Time Difference Questions. Subjects with higher prior knowledge had an average score of 7.70 (SD=3.23) correctly answered time difference questions after learning with animated pictures whereas subjects with static pictures had an average score of only 5.17 (SD=1.95). This difference was significant (t(20)=2.27; p=.017). Subjects with lower prior knowledge had an average score of 6.50 (SD=3.17) correctly answered time difference questions after having learned with animated pictures whereas subjects with static pictures had an average score of only 3.25 (SD=1.49). This difference was highly significant (t(13.3)=2.87; p=.007).Thus, the learning results of the time difference questions provided significant and highly significant support to hypotheses E2 and F2.

Learning Results: Circumnavigation Questions. When subjects had higher prior knowledge those who learned with static pictures surprisingly performed better (M=7.92; SD=2.35) in answering circumnavigation questions than subjects with animated pictures (M=7.30; SD=2.63). Although the difference was far from being significant, this result contradicted the expectation of hypothesis E2. When subjects had lower prior knowledge those with static pictures performed also better (M=7.63; SD=2.72) than subjects with animated pictures (M=5.60; SD=1.51). This difference contradicted hypotheses F2 and was marginally significant (t(10.4)=1.89; p=.088). Thus, the learning results of the circumnavigation questions did not support hypothes E2 and F2, but rather indicated a difference in the opposite direction.

Discussion

The *picture observation times* reveal a tendency according to the hypotheses E1 and F1 which assume that animations have different effects for learners with different prior knowledge. Accordingly, animations seem to have an enabling function for learners with higher prior knowledge, because they present additional information and thus allow more cognitive processing than static pictures, if learners have sufficient prior knowledge as a prerequisite. For learners with lower prior knowledge animations seem to have a facilitating function, because they give external support for required cognitive processes and thus make these processes easier to perform.

The learning results regarding answering *time difference questions* give significant and highly significant support to hypotheses E2 and F2, which assume that both learners with higher and learners with lower prior knowledge have better learning results with animations than with static pictures. However, the learning results regarding answering *circumnavigation questions* did not provide any support for these hypotheses, but rather indicated an opposite effect.

Answering time *difference questions* requires knowledge about time coordinates of various cities in the world and the time differences between them. Animated pictures like the one shown in figure 1 could be manipulated by the learner. Subjects could use these pictures to generate a high number of static picture that displayed various time states. Such a large set of different time states might be a good basis to extract information about time differences. In other words: The high performance of the animation group in answering time difference questions could be explained by the enabling function of animated pictures, because the learner can manipulate these pictures, generate a set of specific examples and explore these examples in order to extract additional information which is not available in static pictures. According to the results, this enabling function was effective not only with high, but also with low prior knowledge subjects.

Answering *circumnavigation questions* requires mental simulations. Animated pictures like the one shown in figure 2 provide external support for such simulations. This facilitation might be benficial for learners with too low cognitive prerequisites who would not be able to perform these mental simulations without support. In this case, animations reduce intrinsic cognitive load to a degree that can be handled by the learner with his/her limited cognitive capabilities (Baddeley, 1992; Sweller & Chandler, 1994). The results indicate, however, that facilitation can also have a negative effect. If learners are capable of performing such mental simulations by themselves, then external support makes processing unnecessarily easy and, thus, subjects invest less cognitive effort than in learning from static pictures where subjects have to perform the mental simulations without external support. From the perspective of cognitive load theory, animation can unnecessarily reduce the germane load associated with deeper meaningful cognitive processing (Sweller, 1999; van Merrienboer, 1997). This negative effect of animations seems to be especially pronounced with lower prior knowledge subjects. Obviously, these learners possess already sufficient prerequisites for mental simulations without external support but, due to their still lower prior knowledge, they are more apt to accept the external support provided by animated pictures. Learners with higher prior knowledge seem to invest about the same amount of cognitive effort into mental simulations with animated and static pictures and, thus, are not exposed to the negative effects of animations. Answering circumnavigation questions seems to be affected by the facilitating function of animated pictures. This function can be beneficial for learning, if learners would not be able to perform specific cognitive processes by themselves. However, the facilityting function can also be harmful for learning, if learners who would be able to perform these processes by themselves are hindered in doing so by unnecessary external support.

The results are in line with the assumption that animations can have both an enabling function and a facilitating function and that these functions play different roles for different groups of learners. For learners with higher prior knowledge the enabling function of animations seems to be especially important (which does not exclude that the enabling function can also play some role with lower prior knowledge).For learners with lower prior knowledge the facilitating function of animations seems to be more important. Contrary to hypothesis F2, this facilitating function can have not only positive, but also negative effects. Furthermore, the results suggest that these function play a different role with different kinds of animations. Wheres animated pictures that can be manipulated seem to have primarily an enabling function which was in this study especially important for time difference questions, animated pictures that allow external simulations seem to have primarily a facilitating function which was in this study especially important for circumnavigation questions.

The learning material used in study 1 did not allow to differentiate between the effects of different kinds of animated pictures, because the experimental treatment included both manipulable pictures (like the one in figure 1) and simulation pictures (like the one in figure 2) with the possibility of continuous simulations and of stepwise simulations.In order to investigate the effects of these kinds of animated pictures a second study was conducted.

STUDY 2

Theoretical Assumptions

Study 2 aimed at answering the question whether different kinds of animation have different cognitive functions which result in different learning outcomes. The animations analyzed were manipulation pictures, stepwise simulation pictures and continuous simulation pictures. The manipulation pictures allowed to generate a high number of different time states for explorative purposes as has been shown in figure 1. The stepwise simulation pictures allowed a learner controlled stepwise external simulation of the earth rotation combined with a circumnavigation around the earth in Western or Eastern direction with various speed. These pictures resembled the one shown in figure 2 except that there was no (continuous) simulation button. The continuous simulation pictures allowed continuous external simulation of the earth 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 in Western or Eastern direction of different speed. These pictures resembled the one shown in figure 2 except that there was no stepwise button.

Enabling Function. One can assume that the manipulation pictures have primarily an enabling function because they allow to generate a high number of different time states for explorative purposes. These pictures enable to learn time differences between various cities and, thus, should be especially helpful for answering time difference questions. If one further assumes that the enabling function of animations plays an important role especially with high prior knowledge learners, then one can derive as hypothesis E3 that high prior knowledge learners perform better in answering time difference question after learning with manipulation pictures than after learning with (stepwise or continuous) simulation pictures:

(E3) HIGH PRIOR KNOWLEDGE:
TIME DIFFERENCE MANIP.PICT. > TIME DIFFERENCE SIMUL.PICT.

Facilitating Function. Similarly, one can assume that the simulation pictures have primarily a facilitating function, as they provide external support for mental simulations which are difficult for some learners. Therefore, the facilitating function should have an influence especially on answering circumnavigation questions. The facilitating function of animations can have positive effects, if learners would not be able to perform cognitive processes without external support. From the perspective of cognitive load theory, an animation can reduce intrinsic cognitive load to a degree that can still be handled by the learner (van Merrienboer, 1997; Sweller & Chandler, 1994). If one further assumes that the facilitating function of animations plays an especially important role with lower prior knowledge learners, then one can derive as hypothesis F3a that low prior knowledge learners perform better in answering circumnavigation questions after learning with (stepwise or continuous) simulation pictures than after learning with manipulation pictures:

(F3A) LOW PRIOR KNOWLEDGE:
CIRCUMNAVIGATION SIMUL.PICT . > CIRCUMNAVIGATION MANIP.PICT.

As study 1 has shown, however, the facilitating function of animations can have also negative effects, if learners are prevented from performing relevant cognitive processes by themselves. In this case, the external support through animations makes processing unnecessarily easy and learners perform less cognitive processing than without this kind of support. From the perspective of cognitive load theory, animation can unnecessarily reduce the germane load associated with deeper meaningful cognitive processing (Sweller, 1999; van Merrienboer, 1997). If one further assumes that the facilitating function of animations plays an important role especially with low prior knowledge learners, then one can derive as alternative hypothesis F3b that low prior knowledge learners perform better in answering circumnavigation questions after learning with manipulation pictures than after learning with (stepwise or continuous) simulation pictures:

(F3B) LOW PRIOR KNOWLEDGE:
CIRCUMNAVIGATION MANIP.PICT. > CIRCUMNAVIGATION SIMUL.PICT.

Learner Control. The facilitating function of animations can only have effects on learning if the pace of information display is adapted to the cognitive abilities of the learner. Stepwise simulation pictures avoid cognitive overload insofar as the simulation speed can be controlled by the learner, whereas ontinuous simulation pictures that do not allow to control the speed of simulation imply the danger of extaneous cognitive load due to an inadequate pace of information display (Sweller & Chandler, 1994). If one assumes again that the facilitating function of animations plays an important role especially with low prior knowledge learners, then one can derive as hypothesis F4 that low prior knowledge learners perform better in answering circumnavigation questions after learning with stepwise simulation pictures than after learning with continuous simulation pictures:

(F4) LOW PRIOR KNOWLEDGE:
CIRCUMNAVIGATION STEP.SIMUL.PICT. > CIRCUMNAVIGATION CONT.SIMUL.PICT.

Method

Subjects and Learning Material. Subjects of study 2 were 41 university students who were randomly assigned to 3 groups. 14 subjects were assigned to the manipulation group, 14 were assigned to the stepwise simulation group, and 13 were assigned to the continuous simulation group. Learning material was the same as in study 1 except that the manipulation group received a text that included only manipulation pictures, whereas the stepwise simulation group received a text that included only stepwise simulation pictures and the continuous simulation group received a text that included only continuous simulation pictures.

Procedure and Scoring. The procedure of study 2 was exactly the same as in study 1. Subjects were again assigned according to a median split to a high and a low prior knowledge group. In the final posttest phase, subjects were again required to apply the acquired knowledge in a comprehension test without further access to the learning material or notes. The test included 12 time difference questions and 12 circumnavigation questions. For each subject the number of correctly answered time difference questions and the number of correctly answered circumnavigation questions was determined.

Results

Time Difference Qustions. When subjects had lower prior knowledge, only very low differences were found between the three groups with regard to answering time difference questions. Subjects with manipulation pictures had an average score of 3.14 (SD=2.11), subjects with stepwise simulation pictures had a score of 2.71 (SD=1.25) and subjects with continuous simulation pictures had a mean score of 3.25 (SD=2.12) correctly answered time difference questions. However, when subjects had higher prior knowledge significant differences were found. Subjects with manipulation pictures had an average score of 3.86 (SD=2.03) which was more than twice as high than the average score of subjects with continous simulation pictures (M=1.80; SD=0.84). A test for statistical significance revealed t(8.46)=2.405 (p=.04) for this difference. Subjects with manipulation pictures also outperformed those with stepwise simulation pictures (M=2.71; SD=1.11), although this difference did not reach significance.

Circumnavigation Qustions. When subjects had higher prior knowledge, only very low differences were found between the three groups with regard to answering circumnavigation questions (manipulation pictures: M=5.71; SD=2.43; stepwise simulation pictures: M=5.43; SD=1.81; continuous simulation pictures: M=5.00; SD=2.12), all being far from statistical significance. However, when subjects had lower prior knowledge the manipulation pictures group performed significantly better with an average of 4.86 correctly answered circumnavigation questions (SD=1.35) than the continuous simulation pictures group (M=3.38; SD=1.06). This difference was statistically significant (t(13)=2.386; p=.033). The stepwise simulation pictures group had an average score of 5.00 correctly answered items (SD=1.73) which was not signficantly better than those of the manipulation pictures group. However, the performance of the stepwise simulation group was significantly higher than those of the continuous simulation pictures group (t(13)=2.226; p=.022).

Discussion

The difference between the manipulation group and the continuous simulation group in answering *time difference questions* were in line with hypothesis E3 which assumed that manipulation pictures have an enabling function especially for learners with higher prior knowledge.Learners could use such pictures to generate various time states in oder to extract information about time differences which was then helpful for anwering time difference questions.

The difference between the manipulation group and the continuous simulation group in answering *circumnavigation question*s supported hypothesis F3b which assumed that learners with lower prior knowledge perform better in answering circumnavigation questions after learning with manipulation pictures than after learning with continuous simulation pictures. However, the difference between the manipulation group and the stepwise simulation group did not support hypothesis F3b but showed a non-significant tendency according to hypothesis F3a. A possible interpretationof this result is that the manipulation pictures and the stepwise simulation pictures are more similar than expected insofar as both present a set of static pictures which can be observed and explored by the learner with his/her own pace. Furthermore, the results support hypthesis F4 which assumes that especially learners with lower prior knowledge perform better in answering circumnavigation questions after learning with stepwise simulation pictures than after learning with continuous simulation pictures, because the continuous simulation pictures may cause extaneous cognitive load whereas stepwise simulation pictures avoid cognitive overload by giving the control of presentation to the learner (Sweller & Chandler, 1994).

To summarize, the results suggest that *manipulation pictures* have an enabling function insofar as they allow to generate a large set of static pictures for explorative purposes. In this study, they allowed to analyse a high number of pictures and to extract the included time differences which then was helpful for anwering time difference questions. This function seems to be especially pronounced with high prior knowledge learners because they have sufficient cognitive capacities to use these possibilities provided by animations.

The results also suggest that *continuous simulation pictures* have a facilitating function insofar as they allow to follow an external simulation process which makes the corresponding mental simulations less demanding. This function might be beneficial for learners who would not be able to perform this mental simulation without external support (cf. Mayer, 1997, 2001; Salomon, 1994; Schnotz, Boeckheler & Grzondziel, 1998). However, if learners are able to perform the mental simulation by themselves (which is possible even for subjects who have less prior knowledge than others) the external support can hinder them to perform relevant cognitive processes. Subjects will then have lower performance in answering simulation questions after learning with continuous simulation pictures than after learning with manipulation pictures. This function seems to be especially pronounced – both in its positive and its negative sense – with lower prior knowledge subjects. The results suggest that continuous simulation pictures have a facilitating function especially for lower prior knowledge subjects, although this facilitation proved finally to have negative effects on learning.

Contrary to the expectations included in hypotheses E3, F3a and F3b *stepwise simulation pictures* seem to have not only a facilitating function, but also an enabling function. The stepwise simulation pictures were obviously processed as an ordered set of static pictures rather than as pictures displaying a dynamic process, and learners were more ready to perform mental simulations by themselves.

Finally, the results indicate that continuous *simulations without learner control* of the simulation speed may cause extaneous cognitive load (Sweller & Chandler, 1994). Such load is avoided by stepwise simulation pictures as the simulation speed is controlled by the learner. Similar results have been reported by Mayer and Chandler (2001) who found that learners understand a multimedia explanation better when it is presented in learner-controlled segments rather than as a continuous presentation. According to the result, this effect seems to be especially pronounced with learners who have lower prior knowledge.

GENERAL DISCUSSION

Animated pictures provide more information than static pictures. This additional information seems to have different functions for learning. On the one hand, animations can enlarge the set of possible cognitive processes and, thus, allow the learner to perform more processing than he/she would be able to to perform with static pictures. This is the *enabling function* of animations. On the other hand, animations can make specific cognitive processes easier to perform through external support of the corresponding mental simulations. This is the *facilitating function* of animations.

Different kinds of animated pictures seem to fulfil different functions for learning. *Manipulation pictures*, for example, which allow to generate and display a large number of static pictures showing different states or showing a subject matter from different perspectives, have primarily an enabling function: They enable learners to perform more cognitive processing than he/she would do with static pictures. *Continuous simulation pictures*, which allow to display a dynamic process, have primarily a facilitating function: They provide external support for corresponding mental simulations and, thus, make these mental processes easier to perform.

The different functions of animations seem to be associated to different cognitive prerequisites. *High prior knowledge* learners seem to benefit primarily from the enabling function of animations. *Low prior knowledge* learners seem to benefit primarily from the facilitating function of animations. The facilitating function of animations can be helpful for learners with very low prior knowledge who would not be able to perform the corresponding mental simulations without external support. However, the facilitating function of animations can also be harmful for learners who would be already able to perform the mental simulations by themselves but make use of the unneeded external support and, thus, perform less cognitive processing.

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