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Learning from multimedia presentations: Facilitation function of animations and spatial abilities

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ABSTRACT

Animations may facilitate learning by providing external support for visual–spatial mental processing. Facilitation is challenged by findings that demonstrate involvement of spatial abilities in learning from animations, because this involvement indicates active internal visual–spatial processing. In the present study, learners attended to a system-paced multimedia presentation in which a verbal–auditory explanation was concurrently synchronized either with animation, with static core pictures, or with enriched static pictures that showed additional intermediate steps and arrows indicating motion. Results demonstrated better learning success with animations and with enriched static pictures than with static pictures. Spatial abilities were not substantively related to learning success with animations or with static pictures, but they played a crucial role for learning success with enriched static pictures. It is concluded that active visual–spatial processing was recruited with enriched static pictures. With animations, learning was truly facilitated by external support for visual–spatial mental processing.

Animations are thought to enhance understanding of dynamic phenomena (e.g., biological processes, mechanical systems). However, research has failed to provide conclusive evidence for advantages of animated instructional materials compared to equivalent static images (e.g., Betrancourt, 2005; Hegarty, Kriz, & Cate, 2003; Mayer, Hegarty, Mayer, & Campbell, 2005; Schnotz, Böckheler, & Grzondziel, 1999; Tversky, Morrison, & Betrancourt, 2002; but see Höffler & Leutner, 2007, for a supportive meta-analysis). Animations may facilitate learning because the external presentation supports otherwise effortful mental visual–spatial processing (facilitation function, Schnotz & Rasch, 2005; supplantation, Salomon, 1994). On the other hand, animations may require effortful visual short-term retention and attentional control. An animation is transitory in nature, that is, relevant information disappears as the animation progresses (Mayer & Chandler, 2001), and animations can include perceptually salient, but irrelevant features (Lowe, 1999, 2003).

The cognitive theory of multimedia learning (Mayer, 2005) assumes that a verbal mental model and a visual mental model are formed in working memory when attending to a multimedia presentation. Learning is critically dependent on the constructive formation of referential connections between these models. These constructive cognitive activities depend on the availability of working memory resources. Positive and negative effects of animations are associated with the cognitive costs for forming the visual mental model. The more cognitive resources are required for processing and understanding an animation, the less resources are free for constructive activities.

Internal spatial visualisation abilities—i.e., storing and manipulating mental visual–spatial representations (see Hegarty & Waller, 2005, for a review)—play an important role for learning from external visualisations. If these external visualisations are static pictures, then high spatial abilities allow learners to perform mental animation, i.e., internal dynamic visualisation (Hegarty et al., 2003; Hegarty & Sims, 1994). If these visualisations are dynamic animations, then again learners with high spatial abilities appear to benefit from animations rather than learners with low spatial abilities (Cohen & Hegarty, 2007; Huk, 2006). Mayer and Sims (1994) suggested that high spatial abilities enhance the formation of the visual mental model when attending to a multimedia presentation, leaving more cognitive resources free for the critical constructive activities.

The facilitation function of animations is in conflict with results demonstrating that spatial abilities are critically involved in learning from animations. Whereas facilitation implies reduction of effortful visual–spatial mental processing, the involvement of spatial abilities indicates activation of mental visual–spatial processing. Therefore, facilitation cannot be concluded from a learning advantage of animations alone. Facilitation is existent only if a learning advantage is not substantively related to spatial abilities.

In addition, facilitation may have particular preconditions. Schnotz and Rasch (2005) suggested that learners with low prior knowledge would profit from facilitation. For learners with high prior knowledge,

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facilitation means providing unneeded external support, and this may act detrimental upon learning (redundancy effect, Kalyuga, Chandler, & Sweller, 1998; expertise reversal effect, Kalyuga, Ayres, Chandler, & Sweller, 2003). Moreover, control over a multimedia presentation (Betrancourt, 2005) can compensate for difficulties in mental processing of dynamic visualisations (Tabbers, Martens, & van Meriënboer, 2004). Thus, facilitation effects of visualisations should be evaluated with system-paced multimedia presentations.

In the present study, facilitation is examined with a system-paced multimedia presentation that explained a molecular process in the domain of biology. The system-paced presentation comprised a verbal narration which was synchronized with different kinds of visualisations. In particular, the study tests two different ways to make motion information in the visualisation explicit: animation (animation condition), and static motion indicators such as additional intermediate states and arrows (enriched static pictures condition). It is expected that both of these visualisations can enhance learning in comparison to core static pictures (static pictures condition) in the context of multimedia learning, primarily because they provide explicit, visual motion information. However, these visualisations will differ in the extent to which they require active visual–spatial processing. If animations have a facilitating function, then learning success should not rely heavily on active internal visual processing. Therefore, spatial abilities should not play a critical role in learning with animations. With static visual motion indicators, learning should require active internal visual processing, because the visual static motion indicators are thought to activate and guide mental animation successfully, even with a system-paced presentation. Therefore, spatial abilities will play an important role.

The following hypotheses are stated:

Visualisation and learning. With static pictures, motion information is not visually provided and has to be inferred both from the static pictures and from the verbal narration. Mental visualisation based on these inferences is effortful and restricts working memory resources for further constructive activities. In addition, the mental visualisation might fail due to the limitative system-paced presentation conditions. In contrast, learning about the biological process of ATP synthesis will be more successful with both animations and enriched static pictures, because visual motion information is explicitly provided in these external visualisations.

H1. Participants will learn more about the biological process from animations than from static pictures.

H2. Participants will learn more about the biological process from enriched static pictures than from core static pictures.

Visualisation and the acquisition of process knowledge vs. structure knowledge. The multimedia presentation describes both the biological process of ATP synthesis (process information) as well as the spatial configuration of the elements of the molecule (structure information). Structure information does not comprise dynamic change, it is presented explicitly in all visualisation conditions and does not rely on information about motion. Therefore:

H3. Effects of visualisations will be found for process knowledge, but not for structure knowledge.

Role of spatial abilities in different visualisation conditions. If animations facilitate, then spatial abilities will play only a minor role for learning success. In contrast, if enriched static pictures activate visual–spatial processing through the visual motion indicators, then spatial abilities will play an important role. Likewise, in the static pictures condition, high spatial abilities may enable participants to visualise motion based on their interpretation of the verbal narration and the static pictures. Therefore:

H4. Learning about the biological process of ATP synthesis will not be critically related to spatial abilities in the animation condition. In contrast, learning success will be related to spatial abilities in both conditions with static pictures. That is, experimental conditions will moderate the relation between spatial abilities and learning success.

1. Method

1.1. Participants

Ninety-four students of Saarland University (72 females) took part in the study. Participants were, on average, 25.67 years old ($SD=7.12$). Thirty-four participants took part in the animation condition, 29 participants were in the static pictures condition, and 31 participants took part in the enriched static pictures condition. Participants were paid and gave informed consent.

1.2. Materials

The multimedia presentation explained the structure of the cellular molecule and the processes for the synthesis of ATP (taken from the computer-based Biology training "The Cell", IWF, 2001). A four-minute auditory–verbal narration fully explained both the components of the molecule as well as the synthesis process of ATP. In either condition, a visualisation was synchronized with the narration. Visualisation conditions differed in the extent to which external motion information was provided explicitly. For instance, the central axis of the molecule rotates which causes particular changes in the formation of the head of the molecule. In the animation condition, these formation changes were presented with smooth transitions between critical states. In the static pictures condition, only the critical states of the head were shown without transitions. In the enriched static pictures condition, intermediate states between the critical ones were added to visualize transition, and static arrows indicated the motion of the head elements. The static pictures condition consisted of ten static pictures providing all relevant visual information. These pictures had been used successfully in prior research on system-paced multimedia learning, either with the auditory narration or with the verbal information as written text (Seufert, Schütze, & Brünken, 2009). The enriched static pictures condition consisted of 17 pictures. Motion was additionally indicated by arrows, with all arrows shown when a picture appeared. In either condition, the presentation proceeded automatically according to the synchronized auditory–verbal presentation.

1.3. Measures

Participants' *prior knowledge* was assessed by a test consisting of 9 tasks about the synthesis of ATP (six multiple-choice and three open questions; Cronbach's $\alpha=.62$). The maximum test score was 13. Participants' *spatial abilities* were measured by the paper-folding test and the card-rotation test (Ekstrom, French, & Harmann, 1976). For each test the percentage of correctly solved items related to the total number of items was calculated; the mean of the two scores represented each participant's spatial abilities.

The test on *learning results* was a computer-based test. It comprised eight items on structure knowledge (Cronbach's $\alpha=.67$) and fourteen items on process knowledge (Cronbach's $\alpha=.77$). Items concerned recall, comprehension, and transfer, either as multiple choice items or as open questions. For *structure knowledge*, there were four recall items, three comprehension items and one transfer item. For *process knowledge*, there were two recall items, six comprehension items and six transfer items. All multiple-choice items were scored with one point for each correct decision. The answers to the open question were compared to predefined answers and coded with one point for each

Table 1
Individual differences measures and results on learning per condition.

	Condition					
	Animation		Static pictures		Enriched static pictures	
	M	*(SD)*	*M*	*(SD)*	*M*	*(SD)*
Individual differences						
Prior knowledge	2.47	(2.41)	2.74	(2.45)	2.71	(3.16)
Spatial abilities (%)	71.82	(19.72)	63.97	(21.12)	66.61	(21.75)
Results on learning						
Process knowledge	4.57	(2.89)	2.76	(2.33)	4.55	(3.83)
Structure knowledge	4.82	(2.50)	4.09	(2.13)	4.15	(3.28)

correct answer. The resulting learning score of the process items are referred to as process knowledge (maximum score = 18), while the resulting learning score of the spatial configuration items are referred to as structure knowledge (maximum score = 13).

1.4. Procedure

Participants were tested in groups of about five participants, individually and randomly assigned to the experimental conditions. First, participants completed the tests on prior knowledge and spatial abilities. Second, participants attended individually to the non-interactive multimedia presentation. The computer-based test for learning outcomes started automatically after the learning phase and was administered without time restrictions.

2. Results

2.1. Prior knowledge and spatial abilities

Results of the test on prior knowledge confirmed that participants were novices in the subject matter. The mean score of the test on prior knowledge was $M = 2.63$ ($SD = 2.67$). Prior knowledge correlated positively with learning outcomes, i.e., with process knowledge, $r = .46$; $p < .001$, as well as with structure knowledge, $r = .63$; $p < .001$. Participants answered, on average, to 68% of the items in the spatial abilities tests correctly ($SD = 21\%$). Twenty-five percent of the participants scored 51% correct or lower, and 25% of the participants scored between 85% and 100% correct. Spatial abilities were positively related to acquisition of process knowledge, $r = .35$; $p < .001$, and to acquisition of structure knowledge, $r = .29$; $p < .01$. Neither prior knowledge nor spatial abilities differed with respect to experimental conditions, $F < 1$; *ns*, for prior knowledge, and $F\ (2,91) = 1.174$; *ns*, for spatial ability (see Table 1). Prior knowledge and spatial abilities did not correlate, $r = .11$; *ns*.

2.2. Results on learning: Process knowledge

Participants scored on the process knowledge test between 0 and 13. The impact of experimental conditions (see Table 1 for descriptive results), spatial abilities and prior knowledge on the acquisition of process knowledge was evaluated by means of multiple regression analyses (Aiken & West, 1991). A complete regression model was estimated which included the experimental conditions as a categorical predictor, spatial abilities and prior knowledge as continuous variables, and all interaction terms (West, Aiken, & Krull, 1996; see Table 2). Dummy coding was used to represent the three experimental conditions. The static pictures condition was considered the comparison condition thereby. That is, the dummy coding variable C1 in Table 2 represents the difference between the animation condition and the static pictures condition, and the dummy coding variable C2 represents the difference between the enriched static pictures condition and the static pictures condition. The continuous variables were centered, as recommended by West et al. (1996), converting them into deviation scores (mean = 0). The regression model (Table 2) explained 41% of the variance, $F(11,82) = 5.261$; $p < .001$. A joint contribution of the two predictors C1 and C2 over and above all other predictors was tested by comparing a reduced model (without these predictors) with the complete model. This comparison tests the first-order effect of condition (West et al., 1996) and revealed a significant gain in prediction, $F(2,82) = 4.35$; $p < .05$, with a difference in $R^2 = .06$. The interaction of condition with spatial abilities was tested by comparing a reduced model (without the interaction terms of spatial abilities with C1 and C2, respectively) with the complete model. A trend for an interaction of condition with spatial abilities was obtained, $F(2,82) = 2.375$; $p < .10$, with a difference in $R^2 = .03$. A possible interaction of condition with prior knowledge was tested analogously, however, an interaction was not found, $F < 1$, *ns*. Finally, the three-way interaction was tested analogously, however, no interaction was found, $F < 1$, *ns*.

Considering the effect of the experimental conditions, both C1 and C2 yielded significant contributions to the prediction, meaning that the differences coded in these variables predicted learning success, supportively answering hypotheses H1 and H2. Prior knowledge had a significant impact on learning success, as revealed by the significant regression coefficient for prior knowledge. No such impact was obtained for spatial abilities (Table 2). However, this was due to an interaction between spatial abilities and visualisation condition. The significant spatial abilities × C2 interaction reflects that the slopes of the regression lines for the relation between spatial abilities and learning success differed between the enriched static condition and

Table 2
Multiple regression model for the acquisition of process knowledge from multimedia presentations.

	Non-standardized *b*	(Standard error)	*t*	*p*
Constant	2.75	(0.49)	5.64	.000
C1	1.70	(0.67)	2.54	.013
C2	1.78	(0.68)	2.60	.011
Spatial abilities	0.74	(2.43)	<1	*ns.*
Prior knowledge	0.51	(0.21)	2.40	.019
Spatial abilities × prior knowledge	1.09	(1.17)	<1	*ns.*
Spatial abilities × C1	3.40	(3.43)	<1	*ns.*
Spatial abilities × C2	7.25	(3.37)	2.17	.033
Prior knowledge × C1	−0.14	(0.29)	<1	*ns.*
Prior knowledge × C2	−0.02	(0.26)	<1	*ns.*
Spatial abilities × prior knowledge × C1	−0.01	(1.59)	<1	*ns.*
Spatial abilities × prior knowledge × C2	−0.56	(1.39)	<1	*ns.*

Experimental visualisation conditions, spatial abilities and prior knowledge were entered as predictors in the model.
Note. $R = .64$, $R^2 = .41$. C1, C2: Dummy coding variables representing the three experimental conditions, with C1 representing the comparison between animation and static pictures condition, and C2 representing the comparison between enriched static pictures and static pictures condition.

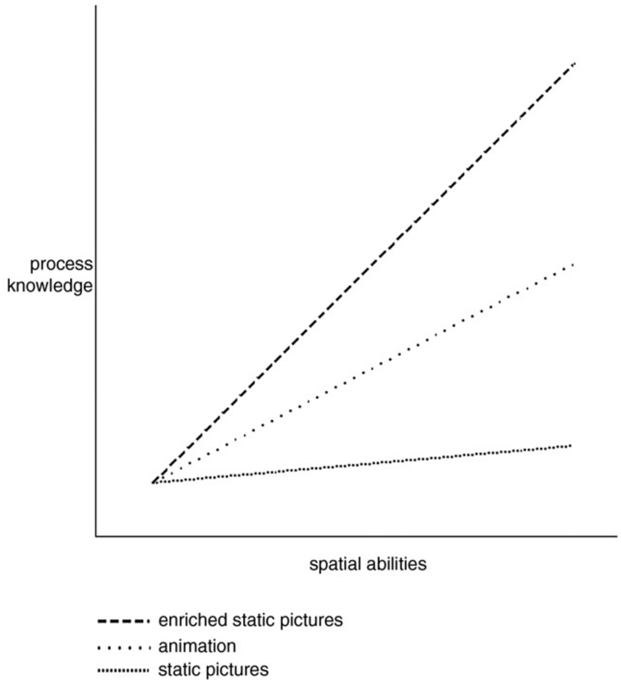

Fig. 1. Slopes indicating the relations between spatial abilities and acquisition of process knowledge in the experimental visualisation conditions (slopes derived from the complete regression model).

the static pictures condition (Fig. 1). In contrast, the slopes between the animation condition and the static pictures condition did not differ, spatial abilities × C1 interaction *ns* (Fig. 1). Hypothesis H4 is partially supported because presentation conditions moderated the relation between spatial abilities and learning success. As expected, spatial abilities were not as important with animations as with enriched static pictures. However, hypothesis H4 did not predict that spatial abilities would be unrelated to learning with static pictures.

2.3. Results on learning: Structure knowledge

Participants scored on the structure knowledge test between 0 and 11.5. Analogous to the analysis for process knowledge, a complete regression model was estimated (see Table 1 for descriptive results). This model explained 49% of the variance, $F(11, 82) = 7.011$; $p < .001$ (see Table 3). The experimental conditions did not contribute significantly to the prediction, as revealed by a comparison of the complete model with a reduced model in which C1 and C2 were removed as predictors, $F = 1.112$; *ns*. Moreover, experimental conditions interacted neither with spatial abilities, $F < 1$; *ns*, nor with prior knowledge, $F < 1$; *ns*, and there was no three-way interaction, $F < 1$; *ns*. Considering the predictions of individual variables and interaction terms, it was found that only prior knowledge contributed significantly to the prediction. Apparently, the acquisition of structure knowledge was dependent on prior knowledge, but it was neither dependent on experimental condition nor on spatial abilities, and predictors did not interact with each other. This result confirms hypothesis H3.

3. Discussion

Differences in learning success between the experimental conditions were found for the acquisition of process knowledge, but not for the acquisition of structure knowledge. Therefore, the discussion focuses on the acquisition of process knowledge.

Results demonstrate that both animations and enriched static pictures enhanced the acquisition of process knowledge in comparison to static pictures. It is suggested that this enhancement was primarily caused by explicit motion information provided in the context of a system-paced multimedia presentation which was attended by learners with low prior knowledge. However, animations and enriched static pictures differed with respect to the cognitive resources required to process the visualisations. A facilitation function of animations was supported by the finding that spatial abilities were not significantly predictive of learning success in the animation condition. It is suggested that animations provided true external support for internal visual–spatial processing. In contrast, spatial abilities were significantly related to learning success in the enriched static pictures condition. It is suggested that the motion information comprised in the enriched static pictures were actively interpreted by mental visual–spatial processes, and that only participants with higher spatial abilities succeeded in this processing such that there were resources free for constructive activities.

Contrary to expectations, spatial abilities were unrelated to learning success in the static pictures condition. It is suggested that it was difficult to mentally animate the biological processes with the static pictures even for learners with high spatial abilities. The static pictures did not provide the explicit *visual* motion information activating and guiding mental animation that the enriched static pictures provided. With a system-paced multimedia presentation, there might be not enough time for the effortful process of mental animation that is based on careful interpretation of the verbal narration and the static pictures. It can be concluded that even learners with high spatial abilities need some support in the visual channel (as provided in the enriched static pictures condition) to successfully learn by means of mental animation with static pictures.

Table 3
Multiple regression model for the acquisition of structure knowledge from multimedia presentations.

	Non-standardized *b*	(Standard error)	*t*	*p*
Constant	4.11	(0.39)	10.621	.000
C1	0.68	(0.53)	1.285	*ns.*
C2	0.01	(0.54)	<1	*ns.*
Spatial abilities	1.56	(1.93)	<1	*ns.*
Prior knowledge	0.53	(0.16)	3.201	.002
Spatial abilities × prior knowledge	0.80	(0.93)	<1	*ns.*
Spatial abilities × C1	0.92	(2.72)	<1	*ns.*
Spatial abilities × C2	2.26	(2.64)	<1	*ns.*
Prior knowledge × C1	−0.11	(0.23)	<1	*ns.*
Prior knowledge × C2	0.16	(0.21)	<1	*ns.*
Spatial abilities × prior knowledge × C1	0.07	(1.26)	<1	*ns.*
Spatial abilities × prior knowledge × C2	−0.58	(1.10)	<1	*ns.*

Experimental visualisation conditions, spatial abilities and prior knowledge were entered as predictors in the model.
Note. $R = .70$, $R^2 = .49$. C1, C2: Dummy coding variables representing the three experimental conditions, with C1 representing the comparison between animation and static pictures condition, and C2 representing the comparison between enriched static pictures and static pictures condition.

In enriched static pictures, two means were used as explicit motion indicators: additional intermediate steps and arrows. Consistent with the present result, Hegarty et al. (2003) found that understanding of a mechanical system was supported by an animation as well as by a series of three static diagrams representing phases of the system, both being more supportive than one static picture. Arrows can indicate motion. In addition, arrows can indicate causal mechanisms. Heiser and Tversky (2006) demonstrated that arrows in a diagram depicting a mechanical system are often interpreted as indicating functional–causal, asymmetric relations. Accordingly, arrows might have activated thinking about causal relations in the present study. Finally, arrows might have served as visual cues that directed the attention of the learner to the relevant portions of the display, avoiding unnecessary searches (e.g., De Koning, Tabbers, Rikers, & Paas, 2007).

The present study can motivate further research on the effects of animations as well as on the effects of static visual means for activating and guiding mental visual–spatial processing. Design considerations for animations with respect to minimizing negative effects need more precision (Ayres & Paas, 2007). Experimental examinations deserve study with preferably objective measures of cognitive load. Considering enriched static pictures, additional intermediate states vs. arrows could be examined separately to test their relative impact on learning. In addition, further research could examine the functions of arrows in more detail. Eye movement studies could particularly be fruitful to underpin the hypothesized attention–direction function. Considering the impact of spatial abilities on learning with multimedia presentations, future research should focus on supporting students with low spatial abilities.

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