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The influence of visual cognitive style when learning from instructional animations and static pictures

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A B S T R A C T

In a 2×2 design, we examined the role of visual cognitive style in two multimedia-based learning environments (text plus static pictures/animations). A statistically significant interaction was obtained for deeper comprehension: Highly developed visualizers (HDV) who learned with static pictures performed better than HDV who learned with animations, and less developed visualizers (LDV) performed the same with static pictures or animations.

For factual knowledge, there was a main effect in favor of HDV. Subsequent tests revealed that HDV outperformed LDV only when learning from static pictures, but not when studying animations. There were no overall differences between animations and static pictures. The assumption is made that HDV benefit from their cognitive style when they have to construct a mental animation from static pictures.

Concluding, we did not find any rationale for converting static pictures to animations — HDV learned better with static pictures, while for LDV, it made no difference.

1. Introduction

Within the whole area of research on multimedia learning a considerable number of studies have been carried out to answer the question whether instructional animations or static pictures might be the better solution for learning and understanding (e.g., Lowe & Schnotz, 2008; Rieber, 1994; Tversky, Morrison, & Bétrancourt, 2002). An important extension of this research is to examine the role of individual learner features more thoroughly (cf. Mayer, 2005, 2009; Schnotz, 2005). Thus, a research focus nowadays lies on specific factors such as *when* and *for whom* one of those multimedia-based learning environments is better suited (Hegarty & Kriz, 2008; Höffler & Leutner, 2007). For instance, prior knowledge has been revealed as an influencing factor in the context of multimedia learning (Kalyuga, 2008). For the comparison of dynamic versus non-dynamic visualizations (i.e., animations versus static pictures), research concerning aptitude-treatment interactions (ATI-effects) has just begun. Whereas there are contradictory results concerning spatial ability (Höffler, Sumfleth, & Leutner, 2006; Huk, 2006; Isaak & Just, 1995) and prior knowledge (ChanLin, 2001; Hegarty & Kriz, 2008; Kalyuga, 2007), no studies have been carried out yet concerning a possible interaction of visual cognitive style when working with animations or static pictures. In the present study, we investigate the influence of visual cognitive style on learning with animations and static pictures.

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2. Theoretical framework

2.1. Learning with text, pictures, and computer-based animations

Various studies based on Mayer's Cognitive Theory of Multimedia Learning (Mayer, 2005) show that the combination of text and pictures promote comprehension and problem-solving transfer (e.g., Mayer, 1997; Yang, Andre, & Greenbowe, 2003).

In modern educational technology dynamic processes are often visualized by animations instead of still images. However, it is still unclear if and when dynamic visualizations have a supportive function in contrast to static pictures — and if the expense of developing an animation is justifiable. Animations are supposed to help learners to imagine processes properly and thus to be able to build up adequate mental representations. A meta-analysis (Höffler & Leutner, 2007) found a significant mean effect size of $d = 0.37$, suggesting an overall superiority of animations over static pictures. This was especially evident when the role of animation was representational, that is, when the topic to be learned is explicitly depicted in the animation. This result could be interpreted in such a way that animations may have the potential to help learners visualizing a process by providing them with a “ready-made” model that can easier be transformed into a mental model than when being provided with static pictures.

On the other hand, many studies did not find animations superior to static pictures (e.g., Lewalter, 2003; Mayer, Hegarty, Mayer, & Campbell, 2005; Swezey, 1991). The prevailing opinion is that animations generally did not fulfill the previously high expectations and thus development expenses often cannot be justified. A coherent review (Tversky et al., 2002) stated that in many cases animations had no learning advantages over static pictures — and if they had, further information had been added. Even for the representation of a continuous change, "clever schematization of static diagrams may be just as effective as animation" (Tversky et al., 2002, p. 258). As to why static pictures may even be superior to animations, it is often argued that an animation does not provide permanent but transitory information (Ainsworth & VanLabeke, 2004; Hegarty, 2004). Static pictures can be revisited a number of times, while animations cannot. Drawing conclusions from Cognitive Load Theory (Sweller, 1994; van Merrienboer & Sweller, 2005), this would impose extraneous cognitive load due to temporal limits of working memory. Consequently, the learner would profit less from animations than from static pictures.

Several moderating effects regarding animations versus static pictures may arise from individual learner features and aptitudes, for example prior knowledge or the visual cognitive style.

2.2. Cognitive style/learning preferences

Derived from Dual Coding Theory (Paivio, 1978, 1986), there is evidence (e.g., Jonassen & Grabowski, 1993; Mayer & Massa, 2003) that while some people are visual learners (*visualizers*), others are verbal learners (*verbalizers*). But there is some inconsistency in the literature as to the nomenclature of the visualizer–verbalizer dimension: Some authors refer to this dimension as a cognitive style (e.g., Richardson, 1977; Riding, 2001) or learning style (e.g., Kirby, Moore, & Schofield, 1988), some to individual learning preferences (e.g., Plass, Chun, Mayer, & Leutner, 1998). Conducting a factor-analysis, Mayer and Massa (2003) identified learning preference, cognitive style, and spatial ability as separate factors. They distinguish between "cognitive ability (i.e., possessing low or high spatial ability), cognitive style (i.e., thinking with words or images), and learning preference (i.e., preferring instruction with text or graphics)" (p. 833). Thus, they clarify the nomenclature by restricting the term "learning preference" only to the act of choosing between verbal or visual material. In this sense, we will assess a cognitive style (for a comprehensive review, see Kozhevnikov, 2007) rather than learning preferences in our study.

In the study of Plass et al. (1998) the combination of text plus pictures or animations in general resulted in better learning outcomes than text alone. But there was a clear ATI-effect that only for visualizers learning success was substantially impaired if pictures or animations were missing. The authors conclude that visualizers profit considerably from visual material, whereas verbalizers depend far less on visual material. Riding and Douglas (1993) could also identify an ATI-effect when confronting visualizers and verbalizers with either text plus pictures or text plus text — visualizers performed better with the text-plus-pictures condition, verbalizers were better with the text-plus-text condition. However, Massa and Mayer (2006) did not find such an effect. Therefore–though intuitively plausible–it is not clear whether verbalizers rely mainly on the textual parts of a multimedia instruction. Likewise to many other ATI-effects, results are inconsistent and quite rare (Biggs, 2001; Cronbach, 2002).

Concerning the difference between animations and static pictures, little research has been conducted yet as to the role of cognitive style. It seems obvious that on this clearly "visual" dimension, a highly or less developed visual style should play a more pronounced role than a visual versus verbal style (although verbalizers and "less developed visualizers" may be congruent to a certain degree). According to the concept of supplantation by Salomon (1979), an animation can be seen as the explicit external representation of a process; such an external model could be quite useful for learners with a less developed visual style to help them develop an adequate mental representation. Accordingly, animations could possess a compensatory illustrative power for learners with less pronounced visual styles or skills (Lewalter, 1997). But while there are some hints that such a compensatory effect could be true for learners with less pronounced visualizing skills in terms of low spatial ability (Höffler et al., 2006), such an effect has not been shown yet for cognitive styles. Though it would be premature to assume a connection between cognitive style and ability (cf. Hannafin & Sullivan, 1996), there is evidence for strong correlations between both variables (Kirby et al., 1988; Massa & Mayer, 2006).

Hence, a possible compensatory effect of animations for–for lack of a better term–"less developed visualizers" (LDV — that is, thinking less in pictures and using less mental images) will be examined in this study. For "highly developed visualizers" (HDV) there are no indications in the literature so far that their learning success would depend on whether visual information is presented to them either in a static or a dynamic way. They should profit from learning material anyway as long as the provided information is presented visually.

3. Method

3.1. Participants

Sixty high-school students (11th graders; 62% female) from several different schools in Germany participated and were randomly assigned and equally distributed to one of two groups (static pictures versus animations). The participants were between 16 and 18 years old. They had little prior knowledge.

3.2. Learning environments

We developed two different versions of a computer-based learning environment using *Toolbook II Instructor* and *Macromedia Director.* The topic of both learning environments was the primary reactions in photosynthesis. The learning environments showed the dynamic processes and causal relationships between these chemical reactions at the thylakoid membranes.

Overall, the learning environments provided 16 static pictures or animations, respectively, in combination with a brief explaining text (not exceeding four sentences per picture/animation; mean: 38 words). According to design suggestions derived from the cognitive theory of multimedia learning, the textual information was closely related to the information given in the associated picture/animation. By clicking on an icon, learners could retrieve the textual information, which was then presented in the middle of the screen (see Fig. 1). The learner had the opportunity to go back page by page to repeat a topic.

Within the static pictures, motions of protons and electrons during the primary reactions were illustrated by arrows as movement indicators. The structure and content of the (self-paced) animations were the same as that of the static pictures; however, no movement indicators were used.

3.3. Measures and questionnaires

3.3.1. Cognitive style

Students' individual cognitive style for visual material was tested by a scale with four items (see Appendix; e.g., "I often use mental images or pictures to help me remember things") deriving from a factor-analysis (Paivio & Harshman, 1983; Urhahne, 2002).[1] It was to

[1] Moreover, a scale for learners' verbal cognitive style was included. As this scale unintentionally also comprised items for self-estimated verbal ability, we decided not to include it in the analyses. Note, however, that there were only very small differences between the groups of "less developed visualizers" (as classified with only the scale on visual cognitive style) and "verbalizers" (as classified with both scales). Again, verbal ability and verbal cognitive style seem to be highly correlated; LDV and HDV differed significantly as to their results on the verbal scale.

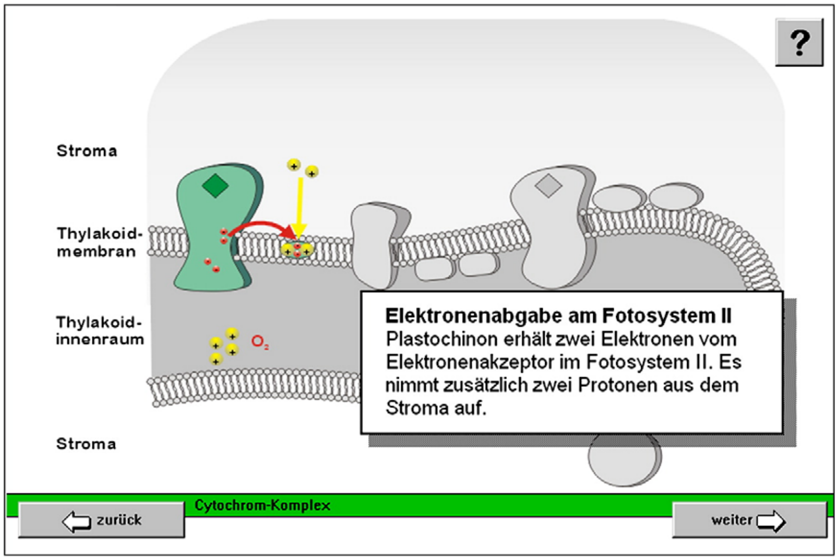

Fig. 1. Exemplary snapshot of a static picture. The additional text has been opened up by clicking on the "?"-button. The text says: "Electron transfer of photosystem II: Two electrons travel along the photosystem II to plastoquinone. Additionally, it uptakes two protons from the stroma".

be answered on a 4-point answering scale (0 = I don't agree … 3 = I strongly agree).

3.3.2. Knowledge

Learners' knowledge was differentiated in factual knowledge (seven items) and deeper comprehension (eight items) about the topic "primary reactions of photosynthesis". It was tested twice with a paper-based questionnaire: at the beginning as *prior knowledge* and at the end of the learning session as *learning outcomes*. While this procedure can be problematic because of the testing effect, the assumed low level of prior knowledge counteracted this possible methodological problem somewhat. All items were available in multiple-choice format (for exemplar items, see Table 1).

3.4. Procedure

Ninety minutes were required for the learning session altogether. Beforehand, the participants were randomly assigned to one of two subgroups (animations/static pictures). All participants filled in a pre-test for approximately 15 min at the beginning of the learning session in which their prior knowledge of the primary reactions of photosynthesis was tested. Cognitive style (in terms of highly developed visual style/less developed visual style) was tested as well. Subsequently, participants had 60 min to work with the computer-based learning environment. Afterwards, learning outcomes were measured in the post-test which took about 15 min.

Table 1
Exemplary items to test factual knowledge and deeper comprehension.

	Exemplary item	Possible answers
Factual knowledge	Which components are not necessary for the primary reactions of photosynthesis?	a) light; chlorophyll b) water; $NADP^+$ c) carbon dioxide; oxygen d) ADP
Comprehension	The pH of the stroma declines from 8.2 to 7.2 in the dark. This fact relies on…	a) $NADPH + H^+$ is produced in the stroma. b) ATP is produced until the gradient of H^+ is reduced. c) Water is splitted at the photosystem II. d) The cytochrome-complex carries protons into the thylakoid lumen.

4. Results

At first, an overall cluster analysis was conducted to divide the students with regard to their cognitive style. This resulted in 27 less developed visualizers (LDV) and 33 highly developed visualizers (HDV). However, they were not quite equally distributed between both conditions; there were 17 LDV and 13 HDV in the static pictures group, while 10 LDV and 20 HDV were in the animation group. Descriptive statistics are shown in Table 2. The reliability for the scale was very satisfying, with a value of Cronbach's alpha of .82.

As expected, the participants had little prior knowledge — for factual knowledge, the mean was $M = 2.70$ (with a possible maximum of 7), $SD = 1.79$; for deeper comprehension, the mean was $M = 2.73$ (possible maximum: 8), $SD = 1.30$. There were no statistically significant differences between the subgroups. However, as there were small correlations between prior knowledge and cognitive style, we chose to control prior knowledge statistically as a covariate in order to reduce within-group error variance and to increase the precision of the experiment (in accordance to suggestions by Field, 2005, and Wildt & Ahtola, 1978).

Data was analyzed within the framework of the General Linear Model (Horton, 1978) with a sequential decomposition of variance. We specified visual cognitive style as the first factor in the model, type of visualization (animation versus static pictures) as the second factor, and the interaction of visual cognitive style and type of visualization as the final effect. Prior knowledge was specified as a covariate. Analyses were separately conducted for dependent measures of factual knowledge and deeper comprehension.

Table 2
Scores on visual cognitive style of less developed (LDV) and highly developed visualizers (HDV): Descriptive statistics.

Cluster	*N*	Visual cognitive style	
		M	*SD*
LDV	27	1.07	0.27
HDV	33	2.22	0.47

Table 3
Descriptive statistics of learning outcomes (factual knowledge) with respect to type of visualization and visual cognitive style. The depicted means are the adjusted means, due to the statistical control of prior knowledge in the analysis.

Type of visualization	Visual cognitive style	N	M	SD
Static pictures	Less developed	17	4.03	1.44
	Highly developed	13	5.12	1.27
	Total	30	4.57	1.37
Animations	Less developed	10	4.35	1.69
	Highly developed	20	4.38	1.44
	Total	30	4.36	1.61
Total	Less developed	27	4.19	1.60
	Highly developed	33	4.75	1.42
	Total	60	4.50	2.14

As to factual knowledge, descriptive statistics are reported in Table 3. No main effect of type of visualization could be found ($F<1$). However, prior knowledge had a significant influence ($F(1,55)=21.44$, $MSE=44.06$, $p<.001$, $\eta^2=0.28$). Furthermore, a main effect of visual cognitive style was obtained ($F(1,55)=6.15$, $MSE=12.64$, $p<.05$, $\eta^2=0.10$): HDV scored significantly higher on factual knowledge than LDV. The interaction between type of visualization and visual cognitive style failed to reach statistical significance ($F(1,55)=1.92$, $MSE=3.94$, $p=.17$, $\eta^2=0.03$). Nevertheless, because we had a specific hypothesis concerning this interaction, an analysis of simple main effects was conducted. It revealed that for animations, HDV and LDV did not differ significantly ($F<1$), whereas HDV scored significantly higher than LDV when using static pictures ($F(1,59)=4.08$, $MSE=8.28$, $p<.05$, $\eta^2=0.07$). On the other hand, there were no significant differences for either HDV ($F(1,59)=1.55$, $MSE=3.24$, $p=.22$, $\eta^2=0.03$) or LDV ($F<1$) between learning with animations or static pictures. Hence, for factual knowledge, animations seem to equal the learning results of HDV and LDV, but mainly for the price of reducing highly developed visualizers' learning success when learning with static pictures (as a significant difference was observed within the static pictures group).

As to deeper comprehension (for descriptive statistics, cf. Table 4), a statistically significant interaction for visual cognitive style by type of visualization was obtained when controlling for prior knowledge as a covariate: $F(1,55)=4.78$, $MSE=12.01$, $p<.05$, $\eta^2=0.08$. Following the significant interaction, simple main effect tests indicated that HDV benefited more from static pictures than from animations ($F(1,59)=4.67$, $MSE=11.61$, $p<.05$, $\eta^2=0.08$). For LDV, the difference between static pictures and animations failed to reach the significance level: $F(1,59)=1.24$, $MSE=3.08$, $p=.27$, $\eta^2=0.02$. Moreover, the difference between HDV and LDV when learning with static pictures was statistically significant ($F(1,59)=4.00$, $MSE=9.97$, $p=.05$, $\eta^2=0.06$), that is, HDV were superior to LDV when using static pictures. For animations, there were no significant differences between HDV and LDV ($F(1,59)=1.66$, $MSE=4.14$, $p=.20$, $\eta^2=0.03$).

Table 4
Descriptive statistics of learning outcomes (deeper comprehension) with respect to type of visualization and visual cognitive style. The depicted means are the adjusted means, due to the statistical control of prior knowledge in the analysis.

Type of visualization	Visual cognitive style	N	M	SD
Static pictures	Less developed	17	2.79	1.59
	Highly developed	13	3.99	1.39
	Total	30	3.39	1.52
Animations	Less developed	10	3.40	1.82
	Highly developed	20	2.74	1.59
	Total	30	3.07	1.76
Total	Less developed	27	3.09	1.74
	Highly Developed	33	3.36	1.55
	Total	60	3.24	2.33

Main effects for visual cognitive style ($F<1$), prior knowledge ($F(1,55)=2.67$, $MSE=6.67$, $p=.11$, $\eta^2=0.05$), and type of visualization ($F(1,55)=1.03$, $MSE=2.58$, $p=.315$, $\eta^2=0.02$), were not statistically significant.

5. Discussion

Our study aims to add another piece to the puzzle, namely: when to use animations or static pictures and for whom. Some studies already reviewed the question of animations versus static pictures in general (Höffler & Leutner, 2007; Tversky et al., 2002). Other studies focused on other individual differences like the role of prior knowledge (e.g., ChanLin, 2001; Szabo & Poohkay, 1996) or spatial ability (e.g., Hays, 1996; Höffler et al., 2006; Narayanan & Hegarty, 2002).

Concerning the role of cognitive style in this respect, however, findings are rather few. We could show an interaction between highly developed visualizers (HDV) and less developed visualizers (LDV) when comparing animations and static pictures. HDV had better results in understanding when learning with static pictures (and were then significantly superior to LDV), while for LDV, it made no difference whether they learned with animations or static pictures.

Interestingly, HDV actually performed worse with animations than with static pictures. This might be explained by the transitory nature of animations, which could produce an extraneous cognitive load.

Another possible explanation as to why especially HDV performed better when learning with static pictures than with animations could arise from the work of Schnotz and Rasch (2005). They reported inhibiting effects of animations for learners who would otherwise be able to perform the mental simulation of a process by themselves. The facilitating effect of the external support hinders them to perform relevant cognitive processes on their own.

Furthermore, in our study LDV could not profit significantly from animations. Thus, animations are seemingly not able to effectively compensate for the presumed lack of LDV to work with visual material by providing them with an adequate dynamic mental model. But as LDV performed worse than visualizers as to factual knowledge and deeper comprehension (when learning with static pictures) they might have been generally overstrained by generating a dynamic mental model from the (non-dynamic) multimedia learning material. Possibly, they concentrated mainly on the textual parts of the multimedia learning environments. This, however, might imply that the “less developed visualizers” of our study are indeed verbalizers. This question should be further investigated with an adequate questionnaire asking for verbal cognitive style.

As to the overall comparison of animations and static pictures, in our study neither animations nor static pictures were generally superior (in contradiction to the results of Höffler & Leutner, 2007). Even more, while for LDV it did not matter whether they used animations or static diagrams, HDV performed better with static pictures. Therefore, in this study no rationale was found for the usage of animations. However, we may have found another cue that a supposed superiority of static or dynamic visualizations may strictly depend on individual characteristics, such as visual cognitive style or prior knowledge (ChanLin, 2001) — if not on some features of the learning environment itself (cp. Höffler & Leutner, 2007).

In order to substantiate our findings that static pictures are especially supportive for visualizers, our results should be replicated in other learning topics. Additionally, spatial ability should be taken into account as there is some evidence for different types of visualizers depending on their level of spatial ability (Kozhevnikov, Hegarty, & Mayer, 2002). Moreover, our study had only 60 participants (and quite low sample sizes in some cells) and therefore did not have much statistical power. Verifying our findings with more participants is recommendable. Furthermore, it still remains an open question how learners with a less developed visual cognitive style (or even verbal cognitive style) can be substantially supported when learning with a multimedia learning environment.

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Appendix A

Visual cognitive style scale comprises four items with a 4-point answering scale (0 = I don't agree … 3 = I strongly agree):

1) I often use mental images or pictures to help me remember things.
2) To understand a process, I imagine the elements of the process.
3) I often use mental pictures to solve problems.
4) I often think in pictures or images.

References

Ainsworth, S., & VanLabeke, N. (2004). Multiple forms of dynamic representation. *Learning and Instruction*, *14*, 241−255.

Biggs, J. (2001). Enhancing learning: A matter of style or approach? In R. J. Sternberg & L. Zhang (Eds.), *Perspectives on thinking, learning, and cognitive style* (pp. 73−102). Mahwah, NJ: Erlbaum.

ChanLin, L. -J. (2001). Formats and prior knowledge on learning in a computer-based lesson. *Journal of Computer-Assisted Learning*, *17*, 409−419.

Cronbach, L. J. (Ed.). (2002). *Remaking the concept of aptitude: Extending the legacy of Richard E. Snow*. Mahwah, NJ: Erlbaum.

Field, A. (2005). *Discovering statistics using SPSS.* London: Sage.

Hannafin, R. D., & Sullivan, H. J. (1996). Preferences and learner control over amount of instruction. *Journal of Educational Psychology*, *88*, 162−173.

Hays, T. A. (1996). Spatial abilities and the effects of computer animation on short-term and long-term comprehension. *Journal of Educational Computing Research*, *14*, 139−155.

Hegarty, M. (2004). Dynamic visualizations and learning: Getting to the difficult questions. *Learning and Instruction*, *14*, 343−351.

Hegarty, M., & Kriz, S. (2008). Effects of knowledge and spatial ability on learning from animation. In R. Lowe & W. Schnotz (Eds.), *Learning with animation: Research implications for design* (pp. 165−180). Cambridge: Cambridge University Press.

Höffler, T. N., & Leutner, D. (2007). Instructional animation versus static pictures: A meta-analysis. *Learning and Instruction*, *17*, 722−738.

Höffler, T. N., Sumfleth, E., & Leutner, D. (2006). The role of spatial ability when learning from an instructional animation or a series of static pictures. In J. Plass (Ed.), *Proceedings of the NYU Symposium on Technology and Learning, April 2006*. New York: New York University.

Horton, R. L. (1978). *The general linear model.* New York: McGraw-Hill.

Huk, T. (2006). Who benefits from learning with 3D models? The case of spatial ability. *Journal of Computer-Assisted Learning*, *22*, 392−404.

Isaak, M. I., & Just, M. A. (1995). Constraints on the processing of rolling motion: The curtate cycloid illusion. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 1391−1408.

Jonassen, D. H., & Grabowski, B. L. (1993). *Handbook of individual differences, learning, and instruction.* Hillsdale: Erlbaum.

Kalyuga, S. (2007). Expertise reversal effect and its implications for learner-tailored instruction. *Educational Psychology Review*, *19*, 509−539.

Kalyuga, S. (2008). Relative effectiveness of animated and static diagrams: An effect of learner prior knowledge. *Computers in Human Behavior*, *24*, 852−861.

Kirby, J. R., Moore, P., & Schofield, N. (1988). Verbal and visual learning styles. *Contemporary Educational Psychology*, *13*, 169−184.

Kozhevnikov, M. (2007). Cognitive styles in the context of modern psychology: Toward an integrated framework. *Psychological Bulletin*, *133*, 464−481.

Kozhevnikov, M., Hegarty, M., & Mayer, R. (2002). Revising the visualizer–verbalizer dimension: Evidence for two types of visualizers. *Cognition & Instruction*, *20*, 37−77.

Lewalter, D. (1997). *Lernen mit Bildern und Animationen: Studie zum Einfluss von Lernermerkmalen auf die Effektivität von Illustrationen. [Learning with pictures and animations: A study about the influence of learner characteristics on the efficiency of illustrations.].* Münster: Waxmann.

Lewalter, D. (2003). Cognitive strategies for learning from static and dynamic visuals. *Learning and Instruction*, *13*, 177−189.

Lowe, R., & Schnotz, W. (2008). *Learning with animation: Research implications for design.* Cambridge: Cambridge University Press.

Massa, L., & Mayer, R. E. (2006). Testing the ATI hypothesis: Should multimedia instruction accommodate verbalizer-visualizer cognitive style? *Learning and Individual Differences*, *16*, 321−335.

Mayer, R. E. (1997). Multimedia learning: Are we asking the right questions? *Educational Psychologist*, *32*, 1−19.

Mayer, R. E. (2005). *The Cambridge handbook of multimedia learning.* Cambridge: Cambridge University Press.

Mayer, R. E. (2009). *Multimedia learning*, Second edition Cambridge: Cambridge University Press.

Mayer, R. E., Hegarty, M., Mayer, S., & Campbell, J. E. (2005). When static media promote active learning: Annotated illustrations versus narrated animations in multimedia instruction. *Journal of Experimental Psychology: Applied*, *11*, 256−265.

Mayer, R. E., & Massa, L. (2003). Three facets of visual and verbal learners: Cognitive ability, cognitive style, and learning preference. *Journal of Educational Psychology*, *95*, 833−841.

Narayanan, N. H., & Hegarty, M. (2002). Multimedia design for communication of dynamic information. *International Journal of Human-Computer Studies*, *57*, 279−315.

Paivio, A. (1978). A dual coding approach to perception and cognition. In H. L. Pick & E. Saltzman (Eds.), *Modes of perceiving and processing information* (pp. 39−52). Hillsdale, NJ: Erlbaum.

Paivio, A. (1986). *Mental representations: A dual-coding approach.* New York: Oxford University Press.

Paivio, A., & Harshman, R. (1983). Factor-analysis of a questionnaire on imagery and verbal habits and skills. *Canadian Journal of Psychology - Revue Canadienne De Psychologie*, *37*, 461−483.

Plass, J. L., Chun, D., Mayer, R. E., & Leutner, D. (1998). Cognitive load in reading a foreign language text with multimedia aids and the influence of verbal and spatial abilities. *Computers in Human Behavior*, *19*, 211−220.

Richardson, A. (1977). Verbalizer–visualizer: A cognitive style dimension. *Journal of Mental Imagery*, *1*, 109−126.

Riding, R. J. (2001). The nature and effects of cognitive style. In R. J. Sternberg & L. Zhang (Eds.), *Perspectives on thinking, learning, and cognitive styles* (pp. 47−72). Mahwah, NJ: Erlbaum.

Riding, R. J., & Douglas, G. (1993). The effect of cognitive style and mode of presentation on learning performance. *British Journal of Educational Psychology*, *63*, 297−307.

Rieber, L. P. (1994). *Computers, graphics, and learning.* Madison: Brown and Benchmark.

Salomon, G. (1979). *Interaction of media, cognition, and learning: an exploration of how symbolic forms cultivate mental skills and affect knowledge acquisition.* San Francisco: Jossey-Bass.

Schnotz, W. (2005). An integrated model of text and picture comprehension. In R. E. Mayer (Ed.), *Cambridge Handbook of Multimedia Learning* (pp. 49−69). Cambridge: Cambridge University Press.

Schnotz, W., & Rasch, T. (2005). Enabling, facilitating, and inhibiting effects of animations in multimedia learning: Why reduction of cognitive load can have negative results on learning. *Educational Technology: Research and Development*, *53*, 47−58.

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction*, *4*, 295−312.

Swezey, R. W. (1991). Effects of instructional strategy and motion presentation conditions on the acquisition and transfer of electromechanical troubleshooting skill. *Human Factors*, *33*, 309−323.

Szabo, M., & Poohkay, B. (1996). An experimental study of animation, mathematics achievement, and attitude toward computer-assisted instruction. *Journal of Research on Computing in Education*, *28*, 390−402.

Tversky, B., Morrison, J. B., & Bétrancourt, M. (2002). Animation: Can it facilitate? *International Journal of Human Computer Studies*, *57*, 247−262.

Urhahne, D. (2002). *Motivation und Verstehen. Studien zum computergestützten Lernen in den Naturwissenschaften. [Motivation and understanding: Studies about computer-based learning in science.].* Münster: Waxmann.

van Merrienboer, J. G., & Sweller, J. (2005). Cognitive load theory and complex learning: Recent developments and future directions. *Educational Psychology Review*, *17*, 147−177.

Wildt, A. R., & Ahtola, O. (1978). *Analysis of covariance.* Sage university paper series on quantitative applications in the social sciences, 07-012. Newbury Park: Sage.

Yang, E. M., Andre, T., & Greenbowe, T. Y. (2003). Spatial ability and the impact of visualization/animation on learning electrochemistry. *International Journal of Science Education*, *25*, 329−349.