The Influence of Presentation Format and Subject Complexity on Learning from Illustrated Texts in Biology

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Abstract: In an experimental study, we investigated how learning from illustrated texts is influenced by presentation format (separated format, integrated format, and active integration) and subject complexity (low, medium and high complexity). Subject matter were biochemical processes of signal transmission in the human nervous system. A total of 180 students participated in the study. Results show that the active integration of texts and illustrations can improve the comprehension of highly complex material, whereas it can have inhibiting effects for less complex material. The results are discussed with respect to the process requirements associated with the different presentation formats.

Introduction

Learning material often consists of different representations. A very common combination of representations is made up of expository texts and illustrations. The beneficial effects of combining texts and illustrations may be attributed to the fact that they complement each other with regard to their content (e.g., Ainsworth, Bibby & Wood, 2002), differ with regard to their computational efficiency (e.g., Larkin & Simon, 1987), or constrain each other's interpretations (Ainsworth, 2006). Although beneficial effects of learning from combinations of texts and illustrations have been frequently observed (e.g., Levie & Lentz, 1982), research has also identified certain difficulties that learners may encounter when processing such combinations. While some of these difficulties seem to be related to the design of the learning material, others seem to be intrinsic to the learners such as their prior knowledge and learning preferences. For instance, it is assumed that the design of learning material may pose unnecessary high processing demands on the learners which, in turn, can lead to an overburdening of their cognitive capacities (e.g., Sweller, van Merriënboer & Paas, 1998). With regard to difficulties intrinsic to the learners, research indicates that particularly those learners with only little prior knowledge may experience difficulties in relating different representations to each other. This seems to be especially true if the learning material is of high complexity (e.g., Bodemer & Faust, 2006; Kozma, 2003). Research also indicates that many learners engage in rather shallow information processing when learning from texts and illustrations (e.g., Peek, 1993).

In all the cases mentioned, learners do not take advantage of the synergetic effects that texts and illustrations may provide them and, as a consequence, fail to construct a coherent mental model of the information presented (cf. Ainsworth et al., 2002). In order to be able to fully exploit the potential of combined texts and illustrations, learners seem to need instructional support (cf. Ainsworth et al., 2002; Bodemer et al., 2004; Hegarty, Carpenter & Just, 1991). At least two approaches aiming at such support can be distinguished. One approach, the *design-oriented approach*, focuses on improving the design of learning material. A second approach, the *engagement-oriented approach*, aims at inducing appropriate mental processes in the learners. In three studies, Bodemer et al. (2004, 2005) demonstrated that learning can be improved by encouraging learners to spatially integrate texts and illustrations by themselves. Because these studies revealed that higher learning gains were associated with higher subject complexity, Bodemer et al. (2004, 2005) assumed that the higher the subject complexity, the more advantageous is learning by integrating texts and illustrations. However, since each study investigated learning in a different domain, the results of the three studies were difficult to compare.

In this paper, we present an experimental study in which we varied the presentation format as well as the subject complexity within the same domain of biology. We begin by outlining the theoretical assumptions and empirical findings within the design-oriented and engagement-oriented approaches. The role of complexity in learning from combined texts and illustrations is then explored. Thereafter, the experimental study and its results are described and discussed.

The Design-Oriented Approach

Research on how to design combinations of texts and illustrations has been highly influenced by two theories: Richard Mayer's *Cognitive Theory of Multimedia Learning* (CTML; Mayer, 2001, 2005) and John Sweller's *Cognitive Load Theory* (CLT; Ayres & Sweller, 2005). CTML takes a process-oriented perspective on learning from combined texts and illustrations. Based on Paivio´s (1986) dual coding theory, and the assumption that human working memory is limited in its capacity (Baddeley, 2003), CTML postulates the following cognitive processes required for successful learning from multimedia: a) selecting relevant information in each presentation, b) organizing the selected information in either a verbal or a pictorial mental model, and c) integrating the verbal and pictorial models as well as prior knowledge by means of mapping processes between corresponding information (Mayer, 2005). Like other conceptualizations of learning from multimedia, CTML considers the integration of verbal and pictorial information to be pivotal for constructing a mental model, which in turn is considered to be important for deep understanding. On the basis of his theory, Mayer (2001) advises that texts and illustrations should be presented in spatial proximity rather than spatially separated. Essentially, it is assumed that spatial proximity facilitates the mental integration of textual and pictorial information. In numerous studies, Mayer and colleagues (e.g., Mayer, 1989; Moreno & Mayer, 1999) were able to demonstrate that a spatially contiguous presentation format leads to more successful learning than does a spatially separated presentation format. This empirical finding has been termed the *spatial contiguity effect*.

As in Mayer's (2001) CTML, it is also assumed in the resource-oriented CLT that human working memory is of limited capacity (e.g., Ayres & Sweller, 2005). According to CLT, three different types of cognitive load may burden working memory during learning: (1) extraneous cognitive load, which results from unnecessary cognitive processes induced by the inappropriate design of learning material; (2) intrinsic cognitive load, which is imposed by subject complexity which, in turn, is determined by the interactivity of elements in the learning material as well as the learners´ prior knowledge; and (3) germane cognitive load, which is related to learning processes such as the construction of concepts and schemata (cf. Ayres & Sweller, 2005).

For a long time, research on CLT has focused on reducing extraneous cognitive load by improving the design of learning material (van Merriënboer & Sweller, 2005). For instance, it is assumed that texts and illustrations which are spatially split induce unnecessary processes such as visual search processes. These processes contribute to extraneous cognitive load and may therefore impede learning. In contrast to Mayer's (2001) CTML, CLT recommends not only to present texts and illustrations together in spatial proximity, but to spatially integrate segments of the texts into the illustrations, resulting in a so-called integrated format. Envision, a text directly positioned above an illustration. From the perspective of CTML, this would correspond to a spatially proximate presentation format because both the text and illustration are presented close to each other. From the perspective of Sweller's CLT, however, this would still correspond to a spatially separated presentation format because the text is not integrated into the illustration. Sweller and colleagues have demonstrated that an integrated format leads to more successful learning than a spatially separated format (e.g., Cerpa, Chandler & Sweller, 1996). They termed this empirical finding the *split-attention effect*. Research also revealed that an integrated format is especially beneficial when the subject complexity is high (e.g., Pollock, Chandler & Sweller, 2002; Ginns, 2006).

A further design principle aimed to reduce extraneous cognitive load and to support the mental integration of verbal and pictorial information is to make the corresponding information in each presentation explicit. This can be achieved by visual indicators such as colour-codes (e.g., Bodemer et al., 2004; Tabbers, Martens & van Merriënboer, 2004), highlighting (e.g., Jamet, Gavota & Quaireau, 2008), or dynamic linking. For example, van der Meij and de Jong (2006) found that learning from dynamically linked presentations is especially beneficial when the subject complexity is high.

Whether corresponding information is made explicit by spatial proximity or by visual indicators, in both cases it is completely up to the learners as to whether or not they engage in the desired selection, organization, and integration processes. Although well-designed learning material may free the learners from unnecessary cognitive processes, thereby making more cognitive capacity available for learning, it is unknown to which degree learners actually take advantage of this capacity. Perhaps learning could be further improved by systematically encouraging the learners to engage in the desired learning processes. Furthermore, various studies indicate that providing learners with well-designed learning material may even act to inhibit learning, since some learners undervalue the complexity and difficulty of the learning material, and therefore exhibit only shallow information processing (e.g., McNamara, Kintsch, Songer & Kintsch, 1996; Schnotz & Rasch, 2005).

The Engagement-Oriented Approach

In contrast to the design-oriented approach, the engagement-oriented approach encourages learners to more actively process the information presented. Various theories of learning, especially constructivist theories, emphasize that the learners' engagement is crucial to successful learning. For example, in Wittrock´s (1992) theory of generative learning, it is assumed that learners do not passively take up and store information, rather they actively search for and process information in order to construct knowledge. Learning thus takes place by actively establishing relations between different pieces of information that are presented to the learners, as well as by establishing relations between new information and prior knowledge. Accordingly, Wittrock's (1992) theory implies that understanding depends on the mental processes actively carried out by the learners.

Various methods have been developed in order to induce and support the learners' engagement in active information processing. Two examples which have been proven to facilitate learning are the production of self-explanations (e.g., Chi et al., 1989; Renkl, 2002) and the visualisation of information present in texts (e.g., van Meter, Aleksic, Schwartz & Garner, 2006). Peek (1993) also recommends instructional interventions which lead to an external and observable product. For instance, various instructions aim at inducing the relevant learning processes by asking the learners to organize textual and pictorial components on the computer screen (e.g., Bodemer et al., 2004).

Bodemer et al. (2004, 2005) developed an instructional method which takes all mentioned aspects into account. They termed this method *active integration*. Initially, learners were presented spatially separated texts and illustrations on a computer screen. They were then asked to move segments of the text to their referential areas in the illustration using the drag and drop method. After completing the task, the learners had constructed a spatially integrated presentation format by themselves. In three experimental studies, Bodemer and colleagues were able to demonstrate that learners who integrated texts and illustrations themselves outperformed learners who were provided with a spatially integrated or a spatially separated presentation format (Bodemer et al., 2004; 2005; Bodemer & Faust, 2006).

Because higher learning gains were attained with higher subject complexity in the studies of Bodemer et al. (2004, 2005), the authors assumed that learning by integrating texts and illustrations may be more successful as the subject complexity increases. This assumption is in line with findings concerning the split-attention effect (cf. Ginns, 2006): while learning from an integrated format is most beneficial if the subject complexity is high, it leads to only small improvements if the subject complexity is low. However, because learning encompassed a different subject domain (physics, statistics and mechanics) in each study of Bodemer et al. (2004, 2005), the results of their studies were difficult to compare.

In the following, we present an experimental study which investigates how presentation format and subject complexity influence learning from combined texts and illustrations. In this study, subject complexity is varied systematically within the same subject domain. According to Sweller and Chandler (1994), subject complexity denotes the number of interacting elements that have to be processed simultaneously by the learners. Increases in complexity were achieved by successively adding interacting elements to the learning material.

Experiment

Design

Two factors, each with three variations, were considered: (1) *presentation format* of combined texts and illustrations (separated format, integrated format, active integration) and (2) *subject complexity* (low, medium, high). Dependent variables were retention and comprehension of the learning material. The learners´ working memory capacity was assessed and taken into account as a covariate. Furthermore, the learners´ spatial abilities were also assessed and taken into account as a covariate. Because learning time was not fixed, it was recorded as a further covariate.

Hypotheses

In accord with Bodemer et al. (2004, 2005), we expected that active integration facilitates learning from combined texts and illustrations more than learning from an integrated format. This hypothesis relies on the assumption that active integration induces and supports the learners' engagement. Because such engagement processes are more important with respect to comprehension than to retention, more substantial effects were expected concerning comprehension. In accord with Ayres and Sweller (2005), as well as Mayer (2001), we expected learning from an integrated format to be more beneficial than learning from a separated format; i.e., we expected the split-attention effect. With regard to subject complexity, we expected active integration to be more beneficial, the higher the subject complexity. More substantial effects of subject complexity were expected with respect to comprehension than with respect to retention. These hypotheses rely on the assumption that during learning from complex material learners need more encouragement and support to systematically and comprehensively process the material.

Material

The subject domain was information processes of the human nervous system. Various biochemical processes related to the transmission of signals between neurons were verbally described and graphically illustrated in such a way that the texts and illustrations complemented each other. For each group, the computer-based learning material consisted of an explanatory text and an accompanying illustration which were presented together on a single computer screen. In order to systematically increase the subject complexity, interacting textual and pictorial information was successively added to the material. Learning material of low complexity addressed the development of resting potentials within the human nervous system (cf. Figure 1). Learning material of medium complexity additionally described the development of action potentials. Processes involved in resting potentials and those involved in action potentials influence each other. Therefore, the processes described in the material of medium complexity did not only complement the processes described in the material of low complexity but the former interacted with the latter. Learning material of high complexity additionally described processes of inhibiting action potentials (cf. Figure 2) which, again, interacted with processes described in the material of low and medium complexity.

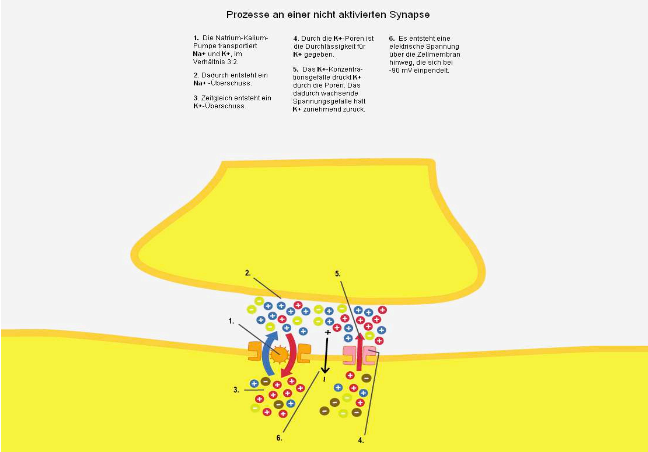

Figure 1. Learning material of low complexity in a separated format.

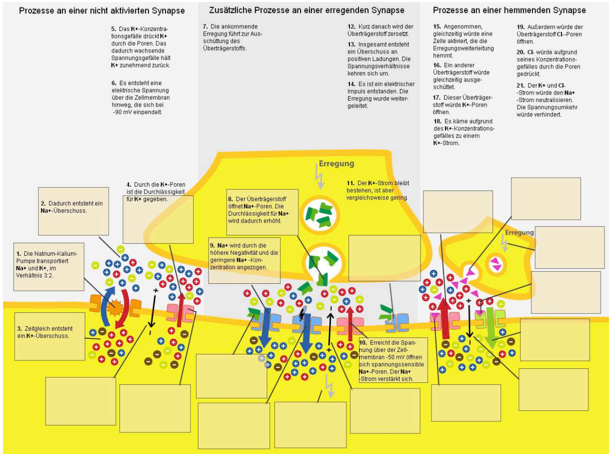

Figure 2. Learning material of high complexity with active integration.

Figure 1 also shows an example of the separated format (SF). Each text segment and corresponding part of the illustration were numbered according to the reading sequence. In the integrated format (IF), the text segments were placed next to the corresponding parts of the illustration. Active integration (AI) began with a separated format (cf. Figure 2); participants were then required to drag and drop the given text segments onto the appropriate part of the illustration. After having arranged all text segments, participants received feedback. If segments were placed incorrectly, the participants were given two opportunities to revise their integration. In the end, the participants were presented with the correct integrated format.

All participants received a short introductory text about the general structures and processes within the human nervous system. On the basis of four multiple-choice questions, participants who did not properly process the introductory text were excluded from the study; at least two of the the four questions had to be answered correctly. To familiarize participants in the active integration group with dragging and dropping text segments, they received an introduction to this functionality.

A pre-test of the participants´ prior knowledge was made up of eight multiple-choice questions which addressed the learning material. Three overlapping post-tests were constructed addressing respectively the low, medium and high complex learning material. All post-tests were comprised of questions relating to retention and comprehension. Both types of questions were constructed in such a way that the correct answers required the mental combination of verbally and pictorially presented information. Whereas questions on retention asked for the recall of information explicitly presented in the learning material, questions on comprehension demanded the participants to draw inferences from the information presented. The post-test for low complex material consisted of eight questions on retention and five questions on comprehension. The questions on retention were identical to the questions used in the pre-test. The post-test for medium complex material was comprised of eleven questions on retention and seven questions on comprehension. In the case of retention, five questions were identical to questions of the post-test for low complex material and six questions were new. In the case of comprehension, three questions were identical to questions on the post-test for low complex material and four questions were new. The post-test for high complex material was also comprised of eleven questions on retention and seven questions on comprehension. In the case of retention, seven questions were identical to questions found on the post-test for medium complex material and four questions were new. In the case of comprehension, five questions were identical to questions on the post-test for medium complex material and two questions were new. Pre- and post-tests were administered on the computer. Each item answered correctly was scored with one point.

With respect to the covariates, working memory capacity was assessed by means of the subtest "memorizing digits" from the Wilde Intelligence Test (Jäger & Althoff, 1983). Spatial abilities were assessed by means of three subtests of the System for the Assessment of Performance (Horn, 1983).

Procedure

Participants were investigated in groups of no more than three; they worked, however, individually on the different material. Sessions were structured into five phases. During the first phase, participants took the memory capacity test and the spatial ability test. During the second phase, participants read the introductory text and answered the pertaining questions. They were allowed to keep the text until the post-test started. During the third phase, learners took the pre-test. The learning material was processed in the fourth phase. The amount of learning time could be chosen individually and was recorded by the computer. Finally, during the fifth phase, participants worked on the post-test.

Participants

Overall, 180 students from two different universities in Freiburg, Germany, were randomly assigned to the nine experimental groups. Students of medicine, psychology and the natural sciences did not participate in the study. Two participants were excluded from the study due to insufficient processing of the introductory text. Five participants were excluded due to high prior knowledge: they answered more than 25% of the pre-test questions correctly. Four participants were excluded due to technical problems. Overall, 169 participants remained (age: $M = 22.3$, $SD = 2.4$; gender: 58 males, 111 females).

Results

Prior Knowledge

On average, the participants' prior knowledge was low ($M = .34$ (4.3%), $SD = .62$) and there were no significant differences between groups with respect to prior knowledge ($F(8,160) = 1.18$, *n.s.*). There was also no significant correlation between performance on the pre- and post-test ($r = .03$, *n.s.*). Therefore, prior knowledge was not further considered in the analysis.

Covariates

An analysis of variance with the factors presentation format and subject complexity on learning time revealed a statistically significant effect for subject complexity ($F(2,160) = 130.30$, $p < .01$, $\eta^2_{part} = .62$). There was no statistically significant effect for presentation format ($F(2,160) = 1.13$, *n.s.*). The interaction between the two factors was also not statistically significant ($F(4,160) = 1.55$, *n.s.*). Post-hoc tests indicated that learning from low complex material took significantly less time than learning from medium complex material (Games-Howell, $MD = -5.01$, $SE = .44$, $p < .001$), which, in turn, took significantly less time than learning from highly complex material (Games-Howell, $MD = -3.87$, $SE = .63$, $p < .001$). On average, participants exhibited high spatial abilities ($M = 6.8$ (75.5%), $SD = 1.1$) and medium working memory capacity ($M = 100.9$ (52.3%), $SD = 10.1$). Analyses of variance showed no significant differences between groups, neither for spatial abilities ($F(8,160) = 1.27$, *n.s.*) nor for working memory capacity ($F(8,160) = 1.01$, *n.s.*).

Learning Performance

With respect to highly complex material, descriptive data shows that active integration led to more successful learning than learning from an integrated format, which in turn was superior to learning from a separated format (cf. Table 1). The differences between these conditions were larger for comprehension than for retention. While the descriptive trends for medium complex material were similar to those of highly complex material, the descriptive trends for low complex material reversed.

A multivariate analysis of covariance (MANCOVA) on the dependent variables retention and comprehension was computed; it included the factors presentation format and subject complexity, as well as the covariates spatial ability, working memory capacity and learning time. Overall, it revealed no significant influence of learning time ($F(2,156) = 2.26$, *n.s.*) on post-test results, but significant influences of spatial ability ($F(2,156) = 3.24$, $p < .05$) and working memory capacity ($F(2,156) = 5.90$, $p < .01$). Furthermore, a statistically significant effect was found for subject complexity ($F(4,312) = 3.78$, $p < .01$). The analysis revealed no statistically significant effect for presentation format and no statistically significant interaction effect between subject complexity and presentation format. The main multivariate effect of subject complexity can be attributed to statistically significant differences with respect to retention ($F(2,157) = 3.43$, $p < .05$).

Table 1: The means and standard deviations of the relative solution frequencies in the post test.

		Low complexity	Medium complexity	High complexity
Separated format	Retention	63.1% (23.5%)	72.7% (19.9%)	54.5% (29.1%)
	Comprehension	40.0% (24.3%)	45.1% (28.3%)	42.0% (24.5%)
	Overall	54.2% (20.5%)	62.0% (20.7%)	49.7% (25.1%)
Integrated format	Retention	62.5% (27.0%)	66.0% (23.2%)	59.1% (23.3%)
	Comprehension	38.9% (29.4%)	45.1% (20.4%)	51.4% (22.0%)
	Overall	53.4% (25.3%)	57.9% (20.1%)	56.1% (20.3%)
Active integration	Retention	56.3% (31.0%)	60.5% (27.7%)	61.5% (28.3%)
	Comprehension	28.9% (24.0%)	44.3% (21.7%)	55.5% (23.1%)
	Overall	45.7% (25.8%)	54.2% (22.5%)	59.2% (24.1%)
Overall	Retention	60.7% (26.9%)	66.3% (24.0%)	58.7% (26.5%)
	Comprehension	36.1% (26.0%)	44.8% (23.4%)	49.7% (23.3%)
	Overall	51.3% (23.8%)	58.0% (21.0%)	55.0% (23.0%)

In order to further explore the data, we conducted a trimmed means analysis according to Wilcox (1998). Based on the results in the post-test, the lower 10% as well as the upper 10% of the participants were removed from each group. In the analysis of trimmed means, the covariates learning time, spatial ability, and working memory capacity showed less influence on post-test results than in the analysis of untrimmed means. The most important difference between the two analyses was that the interaction between presentation format and subject complexity reached statistical significance with respect to comprehension ($F(4,121) = 2.52$, $p < .05$, cf. Figure 3). According to a post-hoc simple effects analysis, this interaction results from the changing effects of active integration ($F(2,123) = 7.34$, $p < .001$): The active integration of learning material inhibits learning when subject complexity is low, but facilitates learning when subject complexity is high. The simple effects analysis did not reach statistical significance with respect to the seperated and integrated presentation formats.

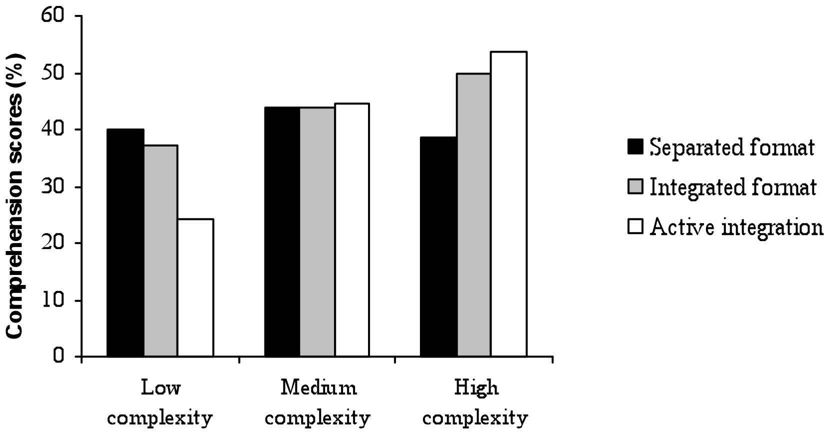

Figure 3. Comprehension scores for the three formats at different levels of complexity.

Discussion

Whether the active integration of texts and illustrations as proposed by Bodemer et al. (2004, 2005) acts to inhibit or to facilitate learning is dependent upon the subject complexity. However, it was only after reducing the variances within groups, that the expected interaction between presentation format and subject complexity was statistically confirmed with respect to comprehension. When subject complexity was high, actively integrating texts and illustrations was of greater benefit than learning from a separated or an integrated format. The active integration of text and illustrations inhibited learning when subject complexity was low. What could have caused this inhibition? It could be that the participants underestimated the difficulty of learning from the low complex material. In the low complex material, the amount of textual and pictorial information was rather small and both types of information were clearly arranged. Requesting the participants to integrate this information might not have led to the intended effortful engagement leading to a deeper understanding of the material, but rather to a more or less “mindless” execution of the drag-and-drop-task (cf. Salomon, 1983). Overall, our findings support, or to say it more carefully, do not contradict the hypothesis of Bodemer et al. (2004, 2005) that learning by integrating texts and illustrations is most successful when the subject complexity is high.

Like Martin-Michiellot and Mendelsohn (2000), as well as Bodemer et al. (2004), we were not able to replicate the split-attention effect - not even with respect to highly complex material. This finding is in contradiction to many studies, especially those by Sweller and colleagues (e.g., Cerpa, Chandler & Sweller, 1996). A comparison of the learning material used, however, reveals two differences. First, in the spatially separated learning material used in many other studies, a more or less unstructured text was combined with an illustration. In many cases, the relevant areas within the illustration were not clearly distinguished. Thus, it was up to the learners to identify meaningful assertions in the text and relevant parts of the illustration, and to then appropriately relate them to each other. In these studies, the separated and integrated formats differed not only with regard to spatial proximity, but with regard to other factors as well such as text segmentation and picture labelling (e.g., Chandler & Sweller, 1991). In contrast, the text in our learning material was always structured into meaningful segments and the relevant areas within the illustration were indicated. It is therefore plausible that our material imposed smaller extraneous cognitive loads on the learners than the material used in other studies. As a consequence, the chance that a split-attention effect would occur was also smaller. From a theoretical point of view, the finding that an integrated format does not lead to better learning than a well-structured separated format supports an explanation put forward by Erhel and Jamet (2006): the beneficial effects of integrated formats result from the explication of relations between texts and illustrations rather than from spatial proximity. A second difference is the design of the pictorial material employed. While Sweller and colleagues (e.g., Sweller & Chandler, 1994) often made use of simple black-and-white line drawings, we employed coloured schematic illustrations comprised of many visual elements. Both colours, as well as the number of visual elements, increase the visual richness of an illustration (cf. Peek, 1993). This difference also could have contributed to a convergence of the extraneous cognitive load imposed on the learners by the separated and integrated formats.

Overall, the differences addressed above indicate that the roles of segmenting text, pointing out relevant parts of illustrations, and designing visual material are underspecified in the context of the split-attention effect. It appears that the distinction between a separated format and an integrated format might not correspond to a clear-cut dichotomy. Martin-Michiellot and Mendelsohn (2000) assume that texts and illustrations can be designed and arranged in such a way that they do not yield an integrated format, but nevertheless support the learner in relating and mentally integrating both presentations. In a recent study, Florax and Ploetzner (in press) found evidence for this assumption: learning from segmented texts and spatially separated pictures improved learning as much as learning from spatially integrated texts and pictures.

The reported study is a first step to clarify the role of active integration for learning from material of different complexity. According to our observations, active integration should only be employed when the subject complexity is high, otherwise it might hinder learning. For example, in the realm of academia, where learning material is usually of high complexity, active integration has the potential to improve learning.

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