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Why do learners who draw perform well? Investigating the role of visualization, generation and externalization in learner-generated drawing

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ABSTRACT

In two experiments, we investigated which of the factors generation, visualization, and externalization mainly contribute to the benefits of learner-generated drawing. We also examined whether benefits of drawing were more pronounced in delayed rather than in immediate testing. To this end, Experiment 1 ($N = 121$) focused on the comparison of the factors visualization and generation, whereas Experiment 2 ($N = 204$) focused on the role of externalization in generative learning activities. In both experiments, participants were asked to read an expository text about biomechanics in human swimming behavior. In Experiment 1, participants were instructed either to construct drawings, to write summaries, to learn with multimedia material, or to only read. In Experiment 2, participants were instructed either to construct drawings, to mentally imagine the content, or to observe a multimedia presentation evolving gradually. Learning outcomes were measured with a recognition, transfer, and drawing test. In Experiment 1, the tests were administered immediately and after one week (within-subjects), whereas in Experiment 2 time of testing was manipulated between subjects. The results of both experiments revealed effects of experimental conditions for transfer and drawing performance, but not for recognition performance. Taken together, the findings indicate that visualization and externalization are the main contributing factors: The drawing and multimedia conditions outperformed the summary and text-only conditions (Exp. 1), thereby supporting the role of visualization, whereas the drawing and observation conditions outperformed the imagery conditions on the drawing test (Exp. 2), thereby emphasizing the role of externalization. There is little evidence that drawing constitutes a desirable difficulty.

1. Introduction

Not just recently, educational researchers have become interested in the effects of learner-generated drawing, a learning strategy during which learners rely on a written text to construct representational drawings that depict the key elements and their relations described in that text (Alesandrini, 1984; Schmeck, Mayer, Opfermann, Pfeiffer, & Leutner, 2014; van Meter, 2001). During drawing, learners engage in generative learning processes while constructing a representation of the learning content that goes beyond what is explicitly stated in the written text, which may result in a deeper understanding of the learning content (Wittrock, 1990). Through drawing, learners are furthermore assumed to create an internal dual code of the learning content, where the written text yields a symbolic (linguistic) mental representation while the learner-generated drawing represents a pictorial code (Paivio, 1986). Finally, learner-generated drawing results in a multimedia representation (Mayer, 2014) of the learning content because the learner's mental representation of the text is externalized onto paper. In sum, there are at least three factors that may play a role during drawing: generation, visualization, and externalization.

In the present study, we compared drawing with other learning strategies that differ from drawing with respect to these factors. This was done to investigate the question of what mainly contributes to the benefit of drawing. Moreover, we examined whether these factors differ in terms of sustainable knowledge that is assessed after a delay rather than immediately after learning.

1.1. What is learner-generated drawing?

In learner-generated drawing learners generate an external pictorial representation that follows two characteristics (Leutner & Schmeck, 2014; van Meter & Firetto, 2013). First, the drawing is representational, that is, the drawing resembles the real-world properties of depicted relevant objects as well as their spatial relations to one another

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(Alesandrini, 1981; Carney & Levin, 2002; van Meter & Firetto, 2013). Second, the drawing is learner-generated, that is, the learner determines both the construction and appearance of the final drawing (van Meter & Garner, 2005). That is, the learner is not a passive consumer of information but is actively involved in the selection, organization, and integration processes during learning. Accordingly, drawing as a learning strategy has been shown to promote learning across a variety of learning domains and age groups (Ainsworth, Prain, & Tytler, 2011; Lesgold, DeGood, & Levin, 1977; van Meter & Garner, 2005).

1.2. Cognitive processes involved in learner-generated drawing

According to the cognitive model of drawing construction (CMDC; van Meter & Firetto, 2013), learners first rely on the text and select key elements from which to build a mental surface representation of the linguistic features of the text. This surface representation is then transferred into a propositional representation that describes structural elements and their relations by organizing the selected elements through semantic processing. A visuo-spatial representation is then derived from the propositional representation and during this process a mental model of the content is built. The propositional representation defines the elements that are included in the mental model, their external appearance, and their relations to one another. Thus, the mental model integrates semantic with visuo-spatial information. Additionally, prior knowledge is applied to the propositional representation and to the mental model. Prior knowledge is particularly important when learners construct a drawing in the absence of any provided pictorial representation. For example, when trying to translate a part of the text reading "The left exterior is convex", learners must consult their long-term memory to determine how the word "convex" can be translated into pictorial form. To construct a drawing, learners translate the mental model into a depictive surface feature representation, that is, the perceptual image that can be externalized onto the page. van Meter and Firetto (2013) postulate that the mental model represents structural relations in a way that allows learners to understand system components and how they work together. Accordingly, drawing fosters assessment of higher-order knowledge (mental model level), for example, when tests measure problem solving (Hall, Bailey, & Tillman, 1997; van Essen & Hamaker, 1990; van Meter, 2001; van Meter, Aleksic, Schwartz, & Garner, 2006), comprehension (Alesandrini, 1981), transfer (Leopold & Leutner, 2012; Schwamborn, Thillmann, Opfermann, & Leutner, 2011; Schwamborn, Mayer, Thillmann, Leopold, & Leutner, 2010), or drawing tests where learners are asked to draw diagrams depicting key concepts (Leopold & Leutner, 2012; Schmeck et al., 2014; Schwamborn et al., 2011). On the other hand, positive effects are not necessarily expected for lower-order knowledge (surface or proposition level), which is in line with empirical research finding no beneficial effects for recognition (van Meter et al., 2006) or factual knowledge (Leutner, Leopold, & Sumfleth, 2009; van Meter, 2001).

1.3. Factors explaining the benefits of drawing as a learning strategy

Compared to just reading text, there are at least three factors that may contribute to the positive effects of drawing as a learning strategy: generation, visualization, and externalization. In the following, we refer to the potential unique contribution of each one of these factors to the overall beneficial effects (see Table 1).

First, learners may benefit from drawing because of the *generation* effect (Foos, Mora, & Tkacz, 1994; Slamecka & Graf, 1978). It means that learners achieve superior performance for information that they generated themselves, among others, because they invested more mental effort processing the information. Specifically, following the Interactive-Constructive-Active-Passive framework (ICAP; Chi & Wylie, 2014), drawing or summarizing text in one's own words are considered constructive activities that stimulate deeper engagement with the learning contents compared to, for instance, just reading text or text with provided drawings. One may argue that reading text is already a constructive activity because readers construct a mental model from the text contents even though they do not have to draw it (e.g., Kintsch, 1998). Chi and Wylie (2014), however, counter-argue that students are more likely to engage in active and constructive learning when such tasks have to be undertaken. Hence, summary writing often led to more accurate metacognition and better learning outcomes compared to just reading text (e.g., Bean & Steenwyk, 1984; Bjork, Dunlosky, & Kornell, 2013; Thiede & Anderson, 2003; Wittrock & Alesandrini, 1990). Similarly, drawing can lead to deeper engagement than reading text that, in turn, should foster learning outcomes, especially when deep understanding or transfer is assessed (see also van Meter & Firetto, 2013; van Meter & Garner, 2005).

Table 1
Contributing factors generation (corresponding to the generation effect), visualization (corresponding to dual coding theory), and externalization (corresponding to the multimedia effect) and their involvement in the learning strategies investigated in the two experiments.

Learning strategy	Contributing factor		
	Generation	Visualization	Externalization
Drawing	yes	yes	yes
Summarizing	yes	no	yes
Mental Imagery	yes	yes	no
Multimedia	no	yes	yes
Observation	no	yes	yes
Text-only	no	no	no

Second, drawing requires a particular type of generation activity; that is, to generate a *visualization*. Hence, it requires generating a new representation (pictorial), in which spatial relations among the concepts described in a text have to be inferred to produce a coherent image – the image may thus include information that goes beyond the provided information and can contain ideas that are not explicitly stated in the text (Chi & Wylie, 2014; Chi, 2009). In contrast to taking verbatim notes or highlighting text, being able to produce a coherent drawing requires deeper understanding of the study contents (mental model level). In consequence, drawing as a learning strategy can be expected to foster learning outcomes by means of deep understanding (not recognition) – especially for those who are able to produce coherent drawings. Accordingly, empirical research shows that learners who construct high-quality drawings – that is, their drawings are complete with regard to the key elements and their relations stated in the text – tend to score higher on learning outcome tests than learners who construct low-quality drawings (Leutner et al., 2009; Mason, Lowe, & Tornatora, 2013; Scheiter, Schleinschok, & Ainsworth, 2017; Schmeck et al., 2014; van Meter, 2001; van Meter et al., 2006). This finding has been referred to as the prognostic drawing effect (Schwamborn et al., 2010). Taking the CMDC into account (van Meter & Firetto, 2013), it seems that beneficial effects of drawing emerge if the test to assess learning outcomes matches the characteristics of the mental model that is constructed through the drawing activity. As a consequence, positive correlations between the quality of constructed drawings and learning outcomes (i.e., the prognostic drawing effect) should depend on the type of test. In particular, correlations for tests that assess higher-order knowledge (transfer, visuo-spatial test) are expected to be higher than correlations for tests that assess lower-order knowledge (retention).

Third, during drawing, this visual representation is not only constructed internally, but is also externalized, thereby resulting in a multimedia representation. According to the multimedia effect, students learn better with multimedia than with text alone (Butcher, 2014; Mayer, 2009). Compared to studying text and mentally imagining the contents, drawing might have an additional beneficial effect because externalizing mental images is cognitively offloading (Ainsworth,