Computers in Human Behavior 25 (2009) 284–289

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

Cognitive load and science text comprehension: Effects of drawing and mentally imagining text content

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ARTICLE INFO

Article history:
Available online 12 January 2009

Keywords:
Cognitive load
Multimedia
Science learning
Text comprehension
Drawing pictures
Mental imagery

ABSTRACT

One hundred and eleven 10th graders read an expository science text on the dipole character of water molecules (ca. 1600 words). Reading instruction was varied according to a 2×2 experimental design with factors 'drawing pictures of text content on paper' (yes, no) and 'mentally imagining text content while reading' (yes, no). The results indicate that drawing pictures, mediated through increased cognitive load, decreased text comprehension and, thus, learning ($d = -0.37$), whereas mental imagery, although decreasing cognitive load, increased comprehension only when students did not have to draw pictures simultaneously ($d = 0.72$). No evidence was found that the effects were moderated by domain-specific prior knowledge, verbal ability, or spatial ability. The results are in line with cognitive theories of multimedia learning, self-regulated learning, and mental imagery as well as conceptions of science learning that focus on promoting mental model construction by actively visualizing the content to be learned. Constructing mental images seems to reduce cognitive load and to increase comprehension and learning outcome when the mental visualization processes are not disturbed by externally drawing pictures on paper, whereas drawing pictures seems to increase cognitive load resulting in reduced comprehension and learning outcome.

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1. Introduction

Recent research on learning with multimedia has revealed that a combination of verbal and pictorial material usually helps learning (the so-called "multimedia effect"; e.g., Mayer, 2001, 2005; Schnotz, 2005). For example, when an expository text is illustrated with suitable pictures which depict the spatial relations of functional elements that are described and discussed in the text (representational visualizations according to Carney & Levin, 2002), students can better comprehend the text – regardless whether it is written on paper or displayed in a hypermedia learning environment.

On the other hand, research on self-regulated learning has revealed that using cognitive and metacognitive strategies also helps learning (Leutner & Leopold, 2006; Pintrich, 2000; Schreiber, 1998; Weinstein & Mayer, 1986). For example, when students have to read an expository text for comprehension and learning, they profit from using cognitive, deep-level learning strategies like text-highlighting or concept mapping (for the latter see, e.g., Hilbert & Renkl, 2009; or Van Gog, Kester, Nievelstein, Giesbers, & Paas, 2009) as well as from controlling the application of their cognitive strategies by using metacognitive strategies like planning and monitoring (Leopold, den Elzen-Rump, & Leutner, 2007; Leutner, Leopold, & den Elzen-Rump, 2007).

Combining ideas of multimedia learning and self-regulated learning, the question arises how learners can improve their understanding when there are no representational pictures included in an expository text. Do instructions that activate learners to generate and construct pictures by themselves enhance text comprehension and, thus, learning? In that case, the construction of pictures can be regarded as the self-regulated application of a cognitive learning strategy. Thus, constructing pictures for understanding, either by drawing them on paper or by simply visualizing them mentally when reading a text, may be called "self-regulated visualizing". For example, Leopold et al. (2007) found that drawing pictures as well as mentally imagining pictures (images) of text content was often spontaneously used when students read a science text (see also van Meter, 2001; van Meter & Garner, 2005, concerning drawing strategies; and Cooper, Tindall-Ford, Chandler, & Sweller, 2001; Kosslyn, 1994, for mental imagery strategies).

Learning from expository texts using a self-regulated visualization strategy (either drawing pictures or mentally imagining text content) seems to be a reasonable learning strategy when pictures are helpful for comprehension, but are not provided in the text. However, visualization strategies might impose high demands on the learner in terms of cognitive load (Ainsworth, 1999). According to cognitive load theory (Paas, Renkl, & Sweller, 2003; Sweller,

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doi:10.1016/j.chb.2008.12.010

1994), three types of cognitive load can be conceptually distinguished from each other: intrinsic cognitive load, extraneous cognitive load, and germane cognitive load. "Intrinsic" cognitive load is induced by the complexity of the subject matter, "extraneous" cognitive load by a deficient instructional design of the learning material, and "germane" cognitive load by cognitive processes that lead to deeper understanding of the learning material. All three types of cognitive load are normally present during learning, and cognitive overload, inhibiting learning, occurs, when the sum of the three loads exceeds the limitations of a student's working memory. From a cognitive-load perspective, it is not intuitively clear, which kind of load is induced by using a self-regulated visualization strategy in learning from a text without pictures, that is, with insufficiently designed instructional material. On the one hand, the visualization strategy might be necessary – at least for some learners – in order to compensate bad instructional design (i.e., text without pictures), thus inducing extraneous cognitive load. This type of load arises because learners are required to transform verbal information into pictorial information which is otherwise provided to them in the learning material when pictures are included. On the other hand, although inducing extraneous load, the visualization strategies – initiated by the instructional design of a text without pictures – can be expected to induce cognitive processes that lead to deeper understanding, thus inducing germane cognitive load.

Another question concerns the role and the specific effect of transforming the verbal information, while reading a text, into a pictorial representation by externally drawing pictures on paper as opposed to mentally imagining pictures without externally drawing them on paper. When *imagining* text content, learners have to mentally transform verbal information into pictorial information which fosters deeper processing. When *drawing* pictures of text content on paper, however, learners have to mentally transform verbal information into pictorial information *and* have to externalize the pictorial information, which is expected to require additional cognitive resources. Furthermore, according to a number of studies (see Zwaan, 2004), generating internal analogue representations can be regarded to be a highly automatic process that facilitates the construction of a mental model and occurs when learners listen to verbal narrations or when reading a text. Thus, it can be expected that using a mental imagery strategy will foster text comprehension without imposing too much cognitive load on the learner. On the other hand, drawing pictures of text content on paper is – for most learners – far from being a strategy that builds upon automatic cognitive processing. In fact, drawing pictures on paper when reading a text might represent a secondary task that imposes additional cognitive load on the learner in general competing with cognitive resources that are otherwise required for accomplishing the primary task of understanding the text and building a suitable mental model of the text content. However, explicit instruction to externally draw pictures when reading a text might help specific learners that are otherwise not able or not used to construct adequate mental images, for example, due to low domain-specific content knowledge or low spatial abilities (see e.g., Mayer, 2001, on prior knowledge and spatial ability as moderators of instructional design). In such cases, concerning visualization strategies, external pictures, drawn by the learner on paper, might facilitate metacognitive processes of mental model quality control that otherwise, when focusing on transient mental images only, are not triggered at all. Thus, although the instruction to draw pictures when reading a text might impose additional extraneous cognitive load at least on some learners, this load might be classified as germane load for other learners because it can trigger metacognitive processes that lead to better text comprehension and better learning (i.e., representing some kind of "expertise reversal" effect, Kalyuga, 2005, or – more general – a specific type of "aptitude–treatment interaction", Cronbach & Snow, 1977, or – even more general – "trait–treatment interaction", Leutner & Rammsayer, 1995).

Thus, it is an open question which role cognitive load plays when using a visualization strategy while reading a non-fictional, expository text without pictures. In order to answer this question, an experimental study was conducted in which the instruction on how to proceed when reading an instructional science text was varied by fostering either internal pictorial representations (mental imagery) and/or external pictorial representations (drawing of pictures) of text content. Furthermore, it was investigated whether the effects of mental imagery and picture drawing on text comprehension are at least to some extent mediated by cognitive load and/or moderated by domain-specific prior knowledge, verbal ability, or spatial ability. Due to the exploratory nature of the study, however, no specific hypotheses were formulated.

2. Method

2.1. Participants

One hundred and eleven German students, 10th graders of a higher track secondary school, participated in the study (56 boys and 55 girls; age $M = 16.1$ years, $SD = 0.44$). Within their classes, students were randomly assigned to one of four treatment conditions with $27 < N < 29$ students per treatment group. The groups are balanced according to students' gender, $\chi^2(3) = 1.24$, $p = .743$.

2.2. Design and materials

The study followed a 2×2 experimental design with drawing instruction (yes, no) and mental imagery instruction (yes, no) as the two experimental factors. Students had to read a science text on the dipole character of water (approximately 1600 words; structured into 13 paragraphs the content of which is depicted in Fig. 1). According to the specific experimental treatment condition, students were instructed to read the text and either to mentally imagine the content of each paragraph of the text while reading the paragraph, to draw pictures on a sheet of paper representing the content of each paragraph of the text, or to do both by imagining the pictures after drawing them. When having to do both, for example, students were instructed to perform three steps for each paragraph of the text to be read: "(1) Read the paragraph, (2) draw a picture that represents the content of the paragraph, and (3) generate a mental image of your picture!" Students of the three treatment conditions were told that their pictures (or images) should be simple and clear and that they should represent the most important information of the paragraph. The pictures (or images) should help them to understand the text. Students of the control treatment condition were instructed to read the text for comprehension only.

The dependent variable was students' amount of text comprehension after having read the text, measured by a multiple-choice test on the content of the science text (22 items with 1–4 correct or false alternatives each; Cronbach's $\alpha = .84$). Item examples are "What is the basic principle of a hydrogen bond? (a) The polar nature of the water molecule, (b) the attraction forces between electrons, (c) the attraction forces between ions, or (d) the polar covalent bond occurring in the water molecule?" and "During hydratation, a 'ion-dipol' attraction is being established. What is meant with this term? (a) Forces between two or more ions, (b) forces between water molecules and ions, (c) forces within water molecules, or (d) forces between the electrons of the ions?" The focus of the test was on comprehension, not on recall, because the

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