Computers in Human Behavior 31 (2014) 73–84

Contents lists available at ScienceDirect

Computers in Human Behavior

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

# Extending multimedia research: How do prerequisite knowledge and reading comprehension affect learning from text and pictures

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ARTICLE INFO

*Article history:*
Available online 30 October 2013

*Keywords:*
Multimedia effect
Modality effect
Redundancy effect
Delayed testing
Reading comprehension
Prerequisite knowledge
Scientific literacy

ABSTRACT

The present study aimed at extending research on multimedia design principles by investigating their validity as a function of learners' reading comprehension and scientific literacy. Students ($N = 125$; age: $M = 15.11$ years) learned about cell reproduction during their regular Biology lessons in one of six conditions resulting from cross-varying multimedia (text only vs. text plus animations) and text modality (spoken vs. written vs. spoken and written). Recall and transfer were assessed immediately after learning and again 1 week later. Overall, adding animations to text as well as using spoken rather than written text improved only immediate recall; in addition, a multimedia effect for delayed recall was observed for learners with higher levels of scientific literacy. A redundant presentation of text proved harmful especially for delayed performance measures. Reading comprehension did not moderate multimedia design effects. Students with more suitable cognitive prerequisites were better able to maintain performance from the immediate to the delayed tests. Future multimedia research should further investigate the boundary conditions that moderate multimedia effectiveness.



## 1. Introduction

Research on learning with text and pictures has yielded numerous recommendations on how to design effective multimedia instruction. For instance, based on converging empirical evidence it has been proposed that (a) adding visualizations to text (i.e., the multimedia principle), (b) using spoken rather than written text to accompany visualizations (i.e., the modality principle), and (c) using spoken rather than written and spoken text (i.e., the redundancy principle) will aid learning (Mayer, 2009). Overall, large median effect sizes have been reported for the multimedia principle, the modality principle, and the redundancy principle. Thus, these design principles have been initially formulated as unconditional rules that were assumed to hold true across a variety of instructional settings and materials. However, lately, research has begun to identify important boundary conditions regarding the emergence of multimedia design effects that have yielded a refinement of these principles.

For instance, with regard to the multimedia principle researchers have investigated whether benefits of adding visualizations to texts are more pronounced for either static or dynamic visualization formats (cf. for reviews Hoeffler & Leutner, 2007; Tversky, Bauer Morrison, & Betrancourt, 2002) or whether they are moderated by the visualization's degree of realism (e.g., Butcher, 2006; Imhof, Scheiter, & Gerjets, 2011; Moreno, Ozogul, & Reisslein, 2011; Scheiter, Gerjets, Huk, Imhof, & Kammerer, 2009). Regarding the modality principle, the benefit of using spoken rather than written text to accompany visualizations has been shown to diminish once learners are allowed to control the pacing of the multimedia instruction (e.g., Gyselinck, Jamet, & Dubois, 2008; Stiller, Freitag, Zinnbauer, & Freitag, 2009; Tabbers, Martens, & van Merriënboer, 2004; Witteman & Segers, 2010) and once longer texts are used (Leahy & Sweller, 2011; Rummer, Schweppe, Fürstenberg, Scheiter, & Zindler, 2011; Schüler, Scheiter, Rummer, & Gerjets, 2012; Wong, Leahy, Marcus, & Sweller, 2012; cf. Schnotz, 2011, for a review of further boundary conditions). Finally, redundancy of written and spoken texts in multimedia presentations has been shown to even be helpful in sequential rather simultaneous multimedia presentations (i.e., when an animation precedes rather than is presented concurrently with the verbal information, Moreno & Mayer, 2002); moreover, redundancy appears to aid learning if the written text consists of labels that help to locate relevant information from the narration in the corresponding visualization (Mayer & Johnson, 2008; Ozcelik, Arslan- Ari, & Cagiltay, 2010).

To conclude, the aforementioned findings suggest that multimedia design recommendations are unlikely to be unconditional rules, since the empirical effects underlying them are moderated by a variety of further multimedia design aspects such as

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http://dx.doi.org/10.1016/j.chb.2013.09.022

visualization design, pacing, text length, as well as temporal and semantic relations between verbal and pictorial information. In the present study, we aimed at further extending this research by investigating if and how learner characteristics rather than design features moderate multimedia design principles. Respective research should allow us to even further refine recommendations on how to design effective multimedia instruction in a given educational context.

### 1.1. The role of individual differences in multimedia learning

Both from a practical as well as from a theoretical perspective it is important to know whether multimedia learning will be effective for all students in the same way. From a practical point of view, observing that a particular multimedia design will, for instance, be helpful only for a specific subgroup of students (e.g., students with a low reading comprehension skills) emphasizes the need for adaptive instruction.

In the context of multimedia learning, different types of aptitude-treatment interactions have been discussed. Mayer and Sims (1994) use the expression ability-as-compensator to denote findings, where cognitive abilities compensate for the otherwise negative effects of poor instruction. Accordingly, no benefits of altering instruction are expected for high-ability learners, whereas low-ability learners are assumed to profit particularly from applying the multimedia design principles. On the other hand, the ability-as-enhancer hypothesis suggests that there will be stronger effects of good instruction for high rather than low-ability learners (Mayer & Sims, 1994).

In the present paper, we were interested in the moderating role of reading comprehension skills and domain-specific prerequisite knowledge assessed in terms of students' scientific literacy in the target domain of Biology.

#### 1.1.1. Reading comprehension

Intuitively, one might argue that skills related to the processing of written text (i.e., reading) should be highly predictive for learning only if the instructional materials are also composed of written text and thus require reading rather than if they consist of additional pictorial information or spoken text (i.e., narration). However, this intuitive view ignores the fact that reading comprehension is dependent on more than just processes related to the encoding of written text such as identifying letters or word decoding; rather, it describes higher-level processes of understanding written discourse (McNamara & Magliano, 2009). Thus, van den Broek (2010) defines reading comprehension as students' ability to construct "a coherent mental representation that integrates the textual information and relevant background knowledge" (p. 453).

Event though models of reading comprehension derive from text comprehension research, "most models assume that their theories generalize to the understanding of information conveyed in discourse, and some hope that their assumptions generalize to the understanding of any media, including visual information" (McNamara & Magliano, 2009, p. 302). According to this view reading comprehension may act as a proxy for a more general comprehension skill that also reflects competencies for processing spoken discourse or nonlinguistic media such as pictures (Gernsbacher, Varner, & Faust, 1990). In line with this view findings from eye-tracking studies suggest that the use of visualizations is largely driven by what has been understood from the text (cf. Hegarty & Just, 1993); hence, reading comprehension should be important in learning from multimedia as well. The question addressed in the present study was whether its influence will differ depending on whether written or spoken text are present and whether visualizations are used to augment the text. Or, to put it differently, will the validity of multimedia design principles be moderated by students' reading comprehension skills? Up to now research investigating if and how reading comprehension affects learning from multimedia is scarce.

With respect to the multimedia effect, there is some evidence that multimedia instruction may be particularly well suited to compensate for a lack of reading skills, thereby aiding especially weaker learners (cf. ability-as-compensator hypothesis acc. to Mayer & Sims, 1994). For instance, story comprehension of poor, but not of good readers in a study by Yuill and Joscelyne (1988) benefitted from pictures that integrated multiple information elements mentioned in the story (see also Holmes, 1987). Importantly, in studies that show an ability-as-compensator effect pictures provided an alternative (redundant) way to extract isolated facts (e.g., regarding the physical appearance of an object). To the authors' knowledge there are no studies using materials that are more typical of those used in multimedia learning, where visualizations are used to convey complex and complementary information regarding spatial, temporal, or causal relationships among various components. Potentially, in these cases good comprehension skills are a prerequisite to understanding visualizations, a view that is more in line with the ability-as-enhancer view (Mayer & Sims, 1994). Tentative support for this assumption was provided by Waddill and McDaniel (1992). The authors investigated the effects of detail and relational pictures for learners at different comprehension levels. Whereas detail pictures illustrated a single fact mentioned in the text, relational pictures served the integration and organization of multiple concepts as well as the depiction of cause-effect chains. The latter were thus more akin to materials used in typical multimedia studies. Less skilled comprehenders showed improved recall for illustrated information compared to a text-only condition if presented with detail, but not with relational pictures, whereas moderately and highly skilled comprehenders benefitted also from relational pictures. These findings suggest that more complex pictures aid learning only if students "already possess the requisite encoding skills" (Waddill & McDaniel, 1992, p. 481). Thus, from these findings it can be concluded that the multimedia effect should become stronger, if learners have better comprehension skills.

With regard to the modality effect, there is only one study to our knowledge that investigated this effect as a function of reading comprehension. Witteman and Segers (2010) found no interaction between reading comprehension and text modality when students were asked to learn from self-paced instructional materials on the formation of lightning. That is, reading comprehension contributed to learning outcomes irrespective of whether students actually had to read or listen to the instructional explanations. Moreover, there was a main effect for text modality suggesting a reversed modality effect, which is likely due to the fact that learners could control the pace of the instruction. Based on these results, we did not expect any moderation of the modality effect due to reading comprehension. This expectation is well in line with the notion that reading and listening comprehension are highly correlated and thus reflect similar constructs (e.g., Gernsbacher et al., 1990; Palmer, MacLeod, Hunt, & Davidson, 1985).

With regard to the redundancy effect, if reading and listening comprehension are highly correlated, then it should possibly also play no role whether narration only or written and spoken text are used to augment visualizations. To the authors' knowledge there are no studies investigating this question yet.

#### 1.1.2. Domain-specific prerequisite knowledge

Beyond reading comprehension, in the present study, students' prerequisite knowledge was assessed. We deliberately use the term prerequisite rather than prior knowledge here, since, importantly, students in our study were complete novices in the domain