Learning and Instruction 36 (2015) 11–26

Contents lists available at ScienceDirect

Learning and Instruction

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

Signals foster multimedia learning by supporting integration of highlighted text and diagram elements

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ARTICLE INFO

Article history:
Received 15 December 2013
Received in revised form
6 November 2014
Accepted 10 November 2014
Available online 27 November 2014

Keywords:
Signals
Multimedia learning
Eye tracking
Visual attention
Integration

ABSTRACT

Two experiments investigated how signals foster learning from text and diagrams by examining the relationship between visual attention and learning outcomes. In Experiment 1 ($N = 55$) students learned about the circulatory heart system from a multimedia lesson either with or without signals highlighting text–diagram correspondences. Results showed that students learning with signals attended to signaled (but not to non-signaled) information more frequently and earlier during learning; these changes in visual attention could explain better performance in answering text–diagram-integration questions. Experiment 2 ($N = 78$) replicated these findings with respect to early attention on signaled diagram elements and learning outcomes; in addition, a third condition was investigated, where signals highlighted diagram elements that did not match the text. Results showed that mismatched signals guided attention only initially, whereas later on students attended more to information that corresponded to the text. Mismatched signals had no effect on learning outcomes. Taken together, the results suggest that signals aid learning by highlighting specific text–diagram correspondences and not by amplifying diagram processing more generally.

1. Introduction

Combining text and diagrams in an instructional message has repeatedly been shown to foster learning compared to studying text only (e.g., Mayer, 2009). During multimedia learning learners have to mentally integrate information conveyed through both external representations into a coherent mental representation. There is, however, evidence that learners often require instructional support to identify the correspondences and to make connections between them (e.g., Seufert, 2003; Seufert & Brünken, 2006).

Signals (or cues) have been one way to help students relate information from text and diagrams to each other. Signals consist of linguistic, typographical, and visual devices that aim at making the structure of an instructional message better accessible to a learner without adding new content-related information to this message (Mautone & Mayer, 2001). Signals thus serve as cognitive aids for learning in that they alter the way that a learner will attend to a message by making relevant information and their interrelations more salient (Lemarié, Lorch, Eyrolle, & Virbel, 2008; Mautone & Mayer, 2001, 2007). Accordingly, using eye tracking researchers have investigated how visual attention (as a proxy for cognitive processing) is affected by presenting signals (e.g., Boucheix & Lowe, 2010; De Koning, Tabbers, Rijkers, & Paas, 2010; Jamet, 2014; Kriz & Hegarty, 2007; Ozcelik, Arslan-Ari, & Cagiltay, 2010; Ozcelik, Karakus, Kursun, & Cagiltay, 2009). However, as will be later discussed findings from these studies are inconclusive with regard to the exact relationship between visual attention and learning outcomes.

Therefore, in two studies we aimed at specifying the mechanisms underlying the signaling effect by investigating the link between visual attention and learning outcomes more closely. This was done both by designing experimental conditions that were suited to disentangle possible explanations of the signaling effect and by deploying statistical procedures suited to determine the degree to which signaling effects on learning outcomes can be explained via changes of visual attention (i.e., mediation analyses, Preacher & Hayes, 2008).

1.1. Using signals to foster integration of text and diagrams

In research on multimedia learning, a variety of signals have been investigated that aim at supporting learners in integrating

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http://dx.doi.org/10.1016/j.learninstruc.2014.11.002
0959-4752/

text and diagrams. In the present paper, we will focus on signals that can be used in static media such as printed books and exclude signals that require interactive or dynamic representation formats (e.g., flashing, Jeung, Chandler, & Sweller, 1997; hyperlinks, Seufert & Brünken, 2006; dynamic cues, Boucheix & Lowe, 2010; De Koning et al., 2010; highlighting of diagram elements in alignment with corresponding narration, Ozcelik et al., 2010).

We were interested in the combined effects of four types of signals to support text–diagram integration, whereby three of the signals highlighted specific correspondences between text and diagrammatic elements (color coding, labeling of the diagram using highlighted words from the text, deixis), while the last signal (paragraph highlighting) was less specific. The specific signals were chosen because they appear to be the ones that are most commonly found in ecologically valid instructional materials such as textbooks as well as the ones that are most commonly found in the research literature. Paragraphing – although extensively used in real instructional materials – appears to have been studied less frequently (for an exception see Stark, 1988), however, it was of interest to us because of the way it linked to other findings in the context of multimedia learning (see below).

In color coding identical colors are used to print words (e.g., terms for a specific concept) and to depict their corresponding diagram elements (e.g., Folker, Richter, & Sichelschmidt, 2005; Kalyuga, Chandler, & Sweller, 1999; Ozcelik et al., 2009). Similarly, labels in diagrams can serve as signals, where words from the text are printed again in the diagram along with a pointer identifying the corresponding element. Despite being redundant to the text, labels have been shown to aid learning (Mayer & Johnson, 2008). In addition, we used deictic expressions as a third way of signaling text–diagram correspondences in the present studies. These deictic expressions were short phrases in the text that pointed the reader towards those elements in the diagram to which the previous sentence referred (e.g., "this can be seen in the middle part of the diagram"). Importantly, also the deictic references were specific in the sense that they highlighted one-to-one correspondences between text and diagram elements rather than guiding the learners' attention to the diagram more generally. Sometimes these text and the diagram elements referred to by deixis consisted of multiple, smaller elements, which were connected via their function and thus built a larger unit. In that case, there was still a one-to-one mapping for each of these smaller elements (cf. systematicity, Gentner, 1983). Finally, we segmented the running text into paragraphs, which was assumed to help learners in identifying the semantic structure of the text (e.g., Goldman, Saul, & Coté, 1995; Stark, 1988). Hegarty and Just (1993) have shown that during learning from text and diagrams successful learners attended to the diagram after having processed larger semantic units of text. Thus, we assumed that highlighting such semantic units by means of paragraphs would increase the propensity of students to search a diagram for corresponding information. Compared with the three aforementioned signaling methods, paragraphing is less specific in terms of the guidance it provides, since it leaves it to the learner to figure out which information elements correspond to each other; rather, it only provides affordances for integration.

Even though these signals appear rather different in terms of their visual implementation in multimedia instruction (i.e., their realization properties according to Lemarié et al., 2008), the signals fulfill the same cognitive function, namely, to help learners identify text–diagram correspondences. This is why we treated the aforementioned signals as interchangeable in terms of their signaling function despite their differences in implementation. The signals' similarity in cognitive function as well as their co-occurrence in ecologically valid information sources (e.g., textbooks) were both reasons to combine these signals in one condition rather than testing the effect of one particular type of signaling in isolation. Analyzing a combination of signals in terms of their shared cognitive function also implies that findings from the studies are relevant also for situations in which signals with yet different realization properties, but the same cognitive function are deployed. For instance, in a classroom a teacher may use a variety of linguistic cues and gestures to highlight correspondences between his/her spoken explanations and a pictorial representation displayed on a whiteboard. Even though these signals may be very different from the ones used in the printed materials in our studies, they can nevertheless be expected to help learners to build a more coherent mental model of the instruction.

1.2. Signals and visual attention

To study whether signals really guide a learner's attention towards corresponding (diagram) information elements by increasing their salience (Lemarié et al., 2008; Mautone & Mayer, 2001) recording a learner's eye movements during learning has become a prominent approach (Scheiter & Van Gog, 2009; Van Gog & Scheiter, 2010).

The popularity of eye tracking in multimedia research emerged from reading research, where it has been used to study the processes of reading for several decades by now (cf. for a review Rayner, 1998). Underlying is the pivotal assumption that the distribution of overt visual attention (i.e., where and for who how long a person attended to information with their eyes) also indicates what is being processed and how long it is being processed at a cognitive level (eye-mind assumption, Just & Carpenter, 1980). Accordingly, if signals affect the distribution of visual attention, this can be interpreted as evidence that they also change cognitive processing.

The most straightforward hypothesis regarding how signals affect visual attention and, in turn, cognitive processing, states that signals guide attention towards those information elements highlighted by them, thereby leading to an increased (cognitive) processing of these elements (i.e., guiding-attention hypothesis, Ozcelik et al., 2010). This should be evident in more time being devoted to processing these elements (i.e., longer overall fixation times and/or longer average fixation durations) as well as more frequent encounters with these elements (i.e., more fixations). Alternatively, it has been suggested that signaling reduces visual search so that the time until relevant elements are fixated for the first time becomes shorter (e.g., the time elapsing between listening to a narration and attending to the corresponding element in the diagram, Jamet, 2014; Ozcelik et al., 2010).

There is evidence for both the guiding-attention hypothesis and the visual-search hypothesis. That is, with signaled materials students have been shown to attend longer and/or more frequently to signaled information elements (e.g., Boucheix & Lowe, 2010; De Koning et al., 2010; Kriz & Hegarty, 2007; Ozcelik et al., 2009, 2010) as well as to focus attention more quickly to the signaled information (Ozcelik et al., 2009, 2010; but see De Koning et al., 2010, for divergent findings). Thus, it can be concluded that signals have an effect on how learners will attend to a multimedia message.

What is less clear though is whether observed changes in visual attention can explain differences in learning outcomes. Sometimes it is just concluded from finding effects of signaling on both, learning outcomes and eye tracking measures, that these effects are causally related each other. Some studies have tried to study the link between visual attention and learning outcomes by calculating correlations between the two types of measures. For instance, Boucheix and Lowe (2010) found positive relationships between the number of fixations on relevant information elements and