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Effects of response prompts and diagram comprehension ability on text and diagram learning in a college biology course

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ABSTRACT

Embedded response prompts are an effective method to support multimedia learning. Response prompts are directives situated within instructional material. Responding to these prompts affects learners' cognitive operations. Different types of prompts affect learning differently due to variations in stimulated cognitive operations. This study compared three types of experimental response prompts; prompts to self-explain the contents of a page, prompts to attend to diagrams and text-diagram relations, and prompts to self-explanation text-diagram relations; and two control conditions. Three tasks that measure verbal text knowledge, diagram knowledge, or knowledge of text-diagram relations assessed learning. The effects of diagram comprehension ability were also considered. A 5 X 3 mixed model ANCOVA revealed an interaction between prompting conditions and posttest tasks. Diagram comprehension ability was associated with task performance but did not interact with conditions.

1. Introduction

College students must often learn from multimedia material that includes both text and diagrams (Mayer, 2014). A biology student learning about skeletal muscle, for example, may read text that identifies key structures and their functions alongside diagrams depicting many of these same elements. This student's learning can be deepened by efforts to comprehend and integrate the text and diagrams (Ainsworth, 1999, 2006). College students who achieve this type of multimedia learning perform better on measures such as problem solving (Berthold, Eysink, & Renkl, 2009) and mental model revision (Butcher, 2006).

Many students do not take full advantage of multimedia, however (e.g., Cromley, Snyder-Hogan, & Luciw-Dubas, 2010; Mason, Pluchino, Tornatora, & Ariasi, 2013). The current study tests methods to improve multimedia learning and factors that may affect this learning. Specifically, we embed different types of response prompts in the material with these prompts intended to affect how learners study multimedia. This research is influenced by the instructional fit hypothesis (Nokes, Hausmann, VanLehn, & Gershman, 2011), which encourages attention to not only the types of response prompts tested but also the tasks that assess learning and relevant individual differences.

1.1. Response prompts and the instructional fit hypothesis

Response prompts are directives situated within instructional material that require the learner to generate some response. A variety of response prompts are possible including adjunct questions, (Hamaker, 1986), metacognitive prompts (Fiorella & Mayer, 2012), and elaboration questions (Van Meter et al., 2016). In the context of multimedia learning, self-explanation prompts are the most frequently studied. These stimulate self-explanation by requiring learners to respond to prompts such as "Why?" questions (Berthold et al., 2009) or directives to explain a particular relationship (van der Meij & de Jong, 2011). Self-explanation supports performance on a variety of tasks (e.g., Litzinger et al., 2010; Schworm & Renkl, 2007) because this strategy increases inference generation (Chi, 2000) and active knowledge construction (Ainsworth & Burcham, 2007). Self-explanation may be particularly well suited to multimedia learning because generated inferences form connections both within and between verbal and nonverbal representations (Wylie & Chi, 2014). Indeed, college students who generate elaborative explanations learn more from text and diagrams than students who self-explain less frequently (Butcher, 2006; Cromley et al., 2010).

Researchers have tested a variety of self-explanation prompts

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(Wylie & Chi, 2014) and, when these comparisons are made within the same study, results generally show that these differences influence learning outcomes (Berthold et al., 2009; Schworm & Renkl, 2007). In a study by van der Meij and de Jong (2011), for instance, participants who were prompted to explain a particular relationship between representations scored higher on measures of conceptual and procedural knowledge than participants who were prompted only to 'explain your answer'. Nokes et al. (2011) proposed the instructional fit hypothesis to account for the varied effects of different response prompts. According to this hypothesis, different prompts stimulate different cognitive operations. Because cognitive operations are responsible for construction of knowledge representations, differences in response prompts lead to qualitative differences in the knowledge that is gained. The effectiveness of any particular prompt then, is determined not by these operations alone, but by the alignment of the constructed knowledge and the tasks that assess learning. This hypothesis also predicts that relevant individual differences interact with prompts and assessment tasks. An individual difference, such as comprehension ability, for instance, could affect how and how effectively a learner executes the cognitive operations stimulated by a particular response prompt.

The current study explores the instructional fit hypothesis in the context of multimedia learning by comparing the benefits of different response prompts across three posttest tasks. The instructional fit hypothesis calls for attention to the cognitive operations that may be affected by different response prompts. Mayer's (2014) Cognitive Theory of Multimedia Learning (CTML) offers a model to identify those operations that are involved in multimedia learning.

1.2. Cognitive operations of multimedia learning

The CTML (Mayer, 2014) identifies selection, organization, and integration as the cognitive operations underlying multimedia learning. A learner provided with text and a diagram selects key elements from the text and then organizes these into a coherent internal representation. Likewise, key elements from the diagram must be selected and organized into a representation of nonverbal knowledge. The cognitive operations of integration connect across corresponding portions of verbal and nonverbal representations as well as generating inferences that draw links within representations and between new and prior knowledge. The result of these operations is construction of a mental model that reflects conceptual understanding and supports transfer. Although selection, organization, and integration can each be separately described, these operations are used recursively and interdependently. While an element must be selected before it can be included in an organized or integrated representation, it is also the case that efforts to construct an organized, integrated representation can lead a learner to select additional elements. In this respect, we expect that a response prompt that affects any one of these operations will also affect the other operations.

The CTML provides a lens through which empirical evidence regarding multimedia learning can be interpreted. One such finding is the multimedia effect, the finding that students who effectively study combinations of text and diagrams perform better on some measures of knowledge than those who study a single representation (e.g., Butcher, 2006; Mason et al., 2013). This effect can be seen when multiple representations are informationally equivalent but computationally different, allowing for different inferences to be made from each representation (Larkin & Simon, 1987). This multimedia effect is consistent with the CTML prediction that knowledge derived from both types of representations are typically superior to those derived from either representation alone (Ainsworth, 1999; Wylie & Chi, 2014).

The multimedia effect notwithstanding, there is substantial evidence that leaners often fail to maximize the potential benefits of combined verbal and nonverbal representations. For example, studies comparing instructional material that provides some support for integrating representations (e.g., hyperlinks) to materials that provide no support, find an advantage for the supported conditions (Seufert, Jänen, & Brünken, 2007; Exp. 3; Bodemer & Faust, 2006; Exp. 2). Furthermore, learners may fail to integrate studied verbal text and visualizations during problem solving (Tabachneck-Schijf & Simon, 1998) and struggle to generate accurate text-diagram connections in the absence of prior knowledge (Bodemer & Faust, 2006; Exp. 1).

While a number of causes may underlie these shortcomings, the focus of this study is on the cognitive operations of multimedia learning. In particular, this study considers two possible reasons that learners struggle to apply selection, organization, and integration to multimedia. First, learners must be aware that these operations are valuable and should be applied. This awareness must include an understanding that diagrams and text-diagram relations should be studied. Unfortunately, empirical evidence suggests learners' may lack diagram awareness. Both eye movement (e.g., Mason et al., 2013) and think aloud (e.g., Cromley et al., 2010) studies demonstrate that multimedia study is largely text driven and many learners put little effort toward text-diagram integration. More optimistically, these same studies show that attention to diagrams improves learning: Learners generate a greater number of higher-order inferences when attending to diagrams than when attending to text (Ainsworth & Loizou, 2003; Cromley et al., 2010) and learners who make more effort to connect text and diagrams score better on higher-order posttests (Butcher, 2006; Mason et al., 2013). Thus, one means to improve learners' execution of multimedia cognitive operations could be to increase their awareness of these operations (Bartholomé & Bromme, 2009; Mason, Pluchino, & Tornatora, 2015).

The second possibility is that learners lack an effective strategy to facilitate the selection of key elements, the organization of these elements, and integration to establish coherence within and between multimedia representations and with prior knowledge. In this case, a leaner may realize that multimedia content should be organized and integrated, but lacks knowledge of just how to achieve this goal. This possibility is consistent with the previously described research on self-explanation, which shows that stimulating learners to self-explain supports multimedia learning (e.g., Berthold et al., 2009; van der Meij & de Jong, 2011). Presumably, because self-explanation requires the selection of to-be-explained elements and generation of organizational and integrative inferences.

There is a third possibility, of course, which is that learners lack both diagram awareness and an effective learning strategy. If this is the case, then neither drawing learners' attention to diagrams nor prompting self-explanation alone will be sufficient to maximize multimedia learning. A learner who employs self-explanation, for instance, may under-utilize multimedia if explanations do not require knowledge derived from diagrams. Likewise, a learner may attend to diagrams but not know how to effectively work with the two representations.

The three experimental prompting conditions tested in this study align with these possibilities. These conditions either direct attention to diagrams and text-diagram relations, prompt self-explanation, or both. Comparisons across these conditions will provide insight into the degree of support learners need to successfully use multimedia. That is, is it sufficient to increase learners' attention to diagrams or do learners require the additional support of being directed to use a particular learning strategy?

In addition to the cognitive operations that may be affected by response prompts, the instructional fit hypothesis also predicts that