Effects of Metacognitive Instructions and Color Coding on Learning from Multiple Representations in Biology

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Keywords: Metacognition; Biology; Self-regulation

Abstract. This study investigated the effects of metacognitive instructions and color coding on learning from verbal and visual representations in biology. Metacognitive instructions directed participants to attend to diagrams and think about the relationship between text and diagrams. These instructions were intended to increase awareness of diagrams and set a goal of constructing an integrated representation during study. Color coding reduced the cognitive demands of multimedia learning. A 2 X 2 experimental design tested these manipulations. College students studied an online tutorial explaining muscle physiology, which contained 2,652 words and 27 diagrams. The multiple-choice posttest measured text knowledge, diagram knowledge, and text-diagram knowledge. Students who studied color coded material obtained significantly higher scores on diagram knowledge items. Students who received metacognitive instructions obtained significantly higher scores on the text-diagram posttest. There were no significant condition effects on posttest items measuring text knowledge.

Introduction

College biology students must learn from materials that contain both verbal text and diagrams. Unfortunately, novice learners often struggle to comprehend and integrate these representations and construct a coherent understanding (Bodemer & Faust, 2006). The research on multimedia learning, which has been designed to address these struggles, has been dominated by efforts to understand instructional design principles that influence student learning (e.g., Kalyuga, Chandler, & Sweller, 1999; Mayer & Moreno, 1998) and interactive manipulations that support integration across representations (e.g., Bodemer, Ploetzner, Bruchmüller, & Häcker, 2005; Seufert & Brünken, 2006.).

There is evidence, however, that students self-regulated learning processes also affect learning from multimedia materials. College students, for example, who are provided self-regulatory prompts acquire more knowledge from hypermedia than do students who do not receive these prompts (Azevedo, Cromley, & Seibert, 2004). Butcher (2006) demonstrated that learners who generated the greatest number of self-explanations while studying text and diagrams acquired more knowledge of the circulatory system.

Studies such as these lead Azevedo and colleagues to propose a model of self-regulated learning in hypermedia environments (e.g., Azevedo et al., 2004) According to this model, a learner must analyze the task, set goals, select and evaluate strategies, and monitor progress. In this study, we tested the effects of drawing students' attention to diagrams during task analysis and setting the goal of representational integration. Specifically, students in metacognitive instructions conditions were told to attend to provided diagrams and think about the relationship between the text and diagrams. These instructions were intended to manipulate students' metacognitive awareness of diagrams and the importance of integrating the verbal and visual representations.

The demands of integration may be too great for students, however. Thus, simply telling students to integrate representations may not lead to improved learning. In this study, we used color coding as a method of reducing these demands. In color coded material, structure labels in both the diagrams and text are shown in the same color font. This manipulation has been shown to reduce the cognitive demands of connecting across representations and improve student learning (Kalyuga et al., 1998).

Methods

Participants and Design

Participants were 124 college students randomly assigned to conditions in a 2(instructions) X 2(coding) design. The first factor compared participants who received metacognitive instructions (MI) to those who did not receive these instructions (noMI). The second factor compared participants who studied color coded materials (CC) to participants who studied non-coded materials (noCC).

Materials

Instructional Materials. Instructional material described the structures of muscles and explained the processes of muscle contraction and relaxation (e.g., motor neurons, end plate potentials, cross-bridge formation, etc.). Text and diagrams were informationally redundant and corresponding diagrams were shown next to text. Diagrams contained verbal labels identifying key structures and processes were illustrated by sequential, static representations of key stages. The text was 2,652 words in length and included 27 diagrams shown in grayscale.

Condition Manipulations. Written metacognitive instructions, given before instructional materials, explained that (1) diagrams show important information and should be inspected, (2) thinking about the relationship between text and diagrams improves learning, and (3) participants should think of these relationships when studying experimental material. Experimenters reviewed these instructions at the start of experimental sessions. Participants in noMI conditions were told to read to understand.

In the CC condition, verbal diagram labels in the instructional material were written in colored font. The same color indicated corresponding elements as each was identified in the verbal text. All diagram labels and text in the noCC condition were in black font.

Prior Knowledge and Posttest Measures. A multiple-choice test assessed prior knowledge on a range of biology topics. No muscle physiology items were included in this assessment.

The posttest was a 41 item multiple-choice test, divided into text-text (T-T), diagram-diagram (D-D), and text-diagram (T-D) subtests (c.f. Bodemer et al., 2005). The subtest was determined by the location of information in the instructional material. On T-T multiple-choice items, both the stem and the choice options were verbal and all information necessary to answer these questions could be found in the text alone. D-D items could be answered with information provided in only instructional diagrams. D-D items include questions requiring identification of a structure or selection of a diagram missing from a sequence. Stems and options in D-D questions were primarily diagrammatic.

T-D items used information from both the text and diagrams to evaluate participants' ability to integrate across verbal and visual representations. One part of these questions (i.e., stem or options) was taken from content contained in either the text or diagram; the second part (i.e., options or stem) was taken from the other source. For example, the stem of one item asked, "…select the diagram that depicts depolarization of the sarcolemma." and options were given as diagrams. This question required that verbal understanding of "sarcolemma depolarization" be matched to an appropriate visual depiction of this state.

Subtests included both factual recall and inferencing questions. There were 14 T-T, 12 D-D, and 15 T-D items. The alpha coefficient for the full test was .69.

Procedures

Participants attended experimental sessions in campus computer labs. The online course management system delivered all materials. Participants completed an informed consent form and a demographic survey to start each session. Instructions appropriate to condition were delivered online. Experimenters drew attention to, and monitored sessions to ensure instructions were read. Participants studied the instructional material and then completed the posttest online.

Results

Table 1 contains percent scores on the post-subtests for the four conditions. There were no significant differences between groups on the prior knowledge measure.

Table 1. Posttest average percent correct and standard deviations across conditions.

	MI/CC	MI/NoCC	NoMI/CC	NoMI/NoCC
T-T posttest items	51 (17)	49 (17)	53 (17)	50 (16)
D-D posttest	52 (18)	41 (22)	46 (21)	39 (14)
T-D posttest	46 (14)	44 (19)	41 (15)	37 (17)

There were no significant differences on the T-T subtest across conditions; CC, $F(1,123) = 0.67$, MI $F(1, 123) = 0.10$, interaction $F(3,120) = 0.02$. There was a significant main effect of CC on D-D items, $F(1,123) = 6.42$, $p<.01$, $\eta^2 = .05$. Neither the main effect of MI nor the interaction was significant on the D-D subtest. Thus, participants who studied color coded instructional material obtained higher scores on test items assessing diagrammatic knowledge than did participants who studied material without the supportive color coding.

There was a significant main effect of MI on the T-D items, $F(1,123) = 3.82$, $p<.05$, $\eta^2 = .03$. Participants who were instructed to think about the relationship between text and diagrams while studying obtained higher scores on posttest items that required integration across these two sources than did participants who did not receive these instructions. There was not a significant main effect of CC on these items, $F(1,123) = 0.92$. The interaction was also nonsignificant, $F(1,120) = 0.17$.

Discussion

In this study, instructions provided prior to study manipulated learners' self-regulatory processes by increasing metacognitive awareness of diagrams and setting the goal of integrating text and diagrams. Students who received these instructions scored higher on a posttest, which assessed the ability to answer questions requiring connections between the text and diagrams. These instructions did not improve students' performance on subtests assessing within-text or within-diagram knowledge, however. Studying color coded material did enhance students' performance on the within-diagram posttest items. These results suggest that reducing the demands of studying diagrams along with text improves students' knowledge of the diagrams but does not support integration of the text and diagrams.

Altogether, the results support the hypothesis that self-regulation affects learning from provided text and visualizations. That there was no interaction between metacognitive instructions and color coding suggests that manipulations, which increase students' attention to diagrams, do not necessarily support the integration of text and diagrams.

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