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

Peggy N. Van Meter [a, *], Chelsea Cameron [b], John R. Waters [c]

[a] Pennsylvania State University, 226 Cedar Bldg., University Park, PA 16803, USA
[b] Pennsylvania State University, 125 Cedar Bldg., University Park, PA 16803, USA
[c] Pennsylvania State University, 208 Mueller Laboratory, University Park, PA 16803, USA

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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

* Corresponding author.
E-mail addresses: pnv1@psu.edu (P.N. Van Meter), cec5144@psu.edu (C. Cameron), jrw8@psu.edu (J.R. Waters).

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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 relevant individual differences will interact with these prompts and tasks. In the context of multimedia learning, one relevant variable is learners' diagram comprehension ability (DCA; Cromley et al., 2013). Surprisingly little research has examined this individual difference in multimedia learning. Yet, DCA is an important variable because, not only do learners often struggle with these representations (Cromley et al., 2013), it is also both proximal and malleable. DCA is proximal because the ability to comprehend diagrams should directly affect the ability to learn from diagrams. DCA is malleable because it can be affected by instruction (Cromley et al., 2013). This study explores how DCA affects multimedia learning and how it may interact with different prompting conditions.

1.3. The current study

In keeping with the instructional fit hypothesis, the current study tests the effects of two variables, type of response prompt and DCA, on different posttest tasks. Participants were students from a college biology course who studied text and diagrams about skeletal muscle. Materials were delivered electronically so that instructions and prompts were embedded in the materials.

The first independent variable, type of response prompt, has five levels including three experimental and two control comparison conditions. The first experimental prompt condition, *diagram awareness* (DA), stimulates the cognitive operations of multimedia learning by increasing learners' attention to diagrams and text-diagram connections. The second experimental prompt condition tests the effects of *self-explanation* (SE) prompts, which direct learners to explain the key ideas in the material. The diagram awareness - self-explanation (DA-SE) condition is the third experimental condition. DA-SE prompts direct participants to explain text-diagram relations.

The two comparison control conditions are *directed response* (DR) and *note-taking* (NT) conditions. The NT condition is a business-as-usual control in which participants are prompted to take notes. Overall, research hypotheses predict that participants in experimental conditions will have higher posttest scores than NT condition participants. Prompts in the DR condition are content-specific, instructor-provided questions similar to adjunct questions. This condition is a stringent test of experimental condition effects because DR prompts should also stimulate selection of key elements and require inference generation. In this respect, we expect DR condition participants to also generate elaborative inferences during study and that the advantage of experimental conditions over the DR condition will be only slight. Inclusion of this condition, however, permits comparisons between prompts that stimulate learning processes (i.e., awareness and strategy use) to prompts that stimulate content-specific processing.

The second independent variable is DCA. The DCA measure used in this study assesses comprehension of geosciences diagrams (Cromley et al., 2013). Geosciences, rather than biology, diagrams were used to reduce the chances that DCA scores would be influenced by biology prior knowledge. Our expectation is that DCA will impact participants' ability to use response prompts and learn from multimedia representations.

The dependent variable, the posttest task, is comprised of three multiple-choice assessments. These assessments, which are modeled after those used by Bodemer and colleagues (e.g., Bodemer & Faust, 2006), use the structure of multiple-choice questions to assess within- and between-representation knowledge. In the Text-Text (T-T) posttest task both the question stem and multiple-choice options are presented as verbal text. The Diagram-Diagram (D-D) task uses diagrams for these question parts and assesses diagram knowledge. The Text-Diagram (T-D) task tests knowledge of text-diagram connections. These items contain both text and diagrams and require learners to determine connections between these representations.

The design of this study is a 5 (prompting condition) X 3 (posttest task) factorial with DCA as a continuous covariate. This is the first study to compare the types of response prompts that we examine here. This is also the first to explore the effects of these prompts across tasks that assess text, diagram, and text-diagram knowledge as well as the potential contributions of DCA. Because of this exploratory quality, we confine our research hypotheses to the expected patterns of major findings. These hypotheses are described below and summarized in Table 1. Although specific research hypotheses address only the major comparisons of this study, Table 1 includes expected rank order of scores to address the comparisons that are not explicitly stated in hypotheses.

Consistent with the instructional fit hypothesis, the main hypothesis of this study predicts a three-way interaction between prompting conditions, DCA, and assessment tasks. Overall, we expect this interaction to follow a pattern in which participants benefit the most when experimental conditions align with learner strengths (e.g., a high DCA participant in the DA condition) and posttest tasks match learning activities (e.g., the T-T task for participants in the verbal SE condition). Given the complex relations embedded in this three-way interaction, our research hypotheses are expressed by the comprising two-way interactions (See Table 1). The first set of hypotheses (H1) correspond to the predicted condition by posttest task interaction. Follow up comparisons decomposing this interaction are expected to reveal the pattern of findings shown as Hypotheses 1a, 1b, and 1c (H1a, H1b, H1c) in Table 1. Specifically, on the T-T task, participants who are prompted to use the verbal self-explanation strategy are expected to have the highest scores with these scores significantly higher than scores for NT condition participants (H1a). On the D-D task, this advantage is expected to shift to participants who receive DA and DA-SE prompts (H1b). On the T-D task, participants in all three experimental conditions are expected to have significantly higher scores than NT condition participants (H1c).

Hypothesis two (H2) predicts a significant condition by DCA interaction showing that higher DCA participants benefit from DA prompts alone but lower DCA participants require the addition of SE prompts. This pattern is expected because high DCA participants should be able to learn from diagrams without the aid of a specific multimedia learning strategy. There are no a priori hypotheses about the effects of DCA in the two control conditions. Hypothesis three (H3) predicts a significant task by DCA interaction such that higher DCA participants have an advantage over lower DCA participants on diagram-based tasks. High DCA participants are expected to learn more from instructional diagrams than low DCA participants.

Three additional hypotheses correspond to expected main effects for each variable. Hypothesis four (H4) predicts that participants in the three experimental groups will have higher total posttest scores than participants in the DR and NT conditions. This prediction is based on the expectation that response prompts stimulate effective multimedia learning operations. Hypothesis five (H5) predicts a significant positive association between DCA and posttest scores. Although a significant condition by DCA interaction is expected to show that high DCA participants' advantage is greatest on diagram-related tasks (H2), DCA is expected to make an overall contribution to the knowledge gained from multimedia. Hypothesis six (H6) predicts that scores on the T-T posttest task will be significantly higher than D-D or T-D scores. This pattern is expected because the T-T task is more familiar than either the D-D or

Table 1
Research Hypotheses and Findings for Interaction Effects

Condition × Task Interaction (Hypothesis 1; H1)
Numbers indicate the expected rank order of scores for Hypotheses 1a, 1b, and 1c

	DA	SE	DA-SE	DR	NT	Expected	Findings
T-T (H1a)	2	1	1	2	3	SE, DA-SE > NT DA, DR > NT	SE > DA-SE, NT
D-D (H1b)	1	2	1	2	3	DA, DA-SE > NT SE, DR > NT	DA > all SE, DA-SE, DR > NT
T-D (H1c)	1	1	1	2	3	SE, DA, DA-SE > NT DR > NT	SE, DA, DA-SE > NT

Condition × DCA Interaction (Hypothesis 2; H2)
DCA shown as dichotomous Hi and Lo to indicate relationship

DA	SE	DA-SE	DR	NT	Expected	Findings
Hi > Lo	Hi = Lo	Hi = Lo	–	–	DA benefits hi DCA SE supports low DCA	Interaction not significant

DCA × Task Interaction (Hypothesis 3; H3)

T-T	D-D	T-D	Expected	Findings
Hi = Lo	Hi > Lo	Hi > Lo	DCA supports performance on tasks with diagrams	Interaction not significant

T-D posttest tasks. This task also aligns better than either the D-D or T-D tasks with the cognitive operations likely to be executed by participants in the three conditions that were not told to attend to diagrams.

2. Methods

2.1. Participants and design

During laboratory data collection sessions, 313 college students from a human physiology course completed the DCA and prior knowledge measures. From the same course, 586 students completed the experimental material as online homework and gave consent for study participation. Participants in this study are 280 students who completed both the laboratory and experimental measures. Students received course extra credit for participation. The course instructor is the third author of this paper. Data is only reported for those students who gave consent to participate in the research.

Participants were 98 females and 181 males; one participant did not indicate gender. The majority was Caucasian (80%) but the population also included 8% African-American, 9% Asian, and 4% Hispanic participants. Twelve participants reported multiple ethnic groups and 2.5% selected ‘other’. Most participants were STEM majors in their first year of college.

The experimental multimedia tutorial was assigned as course homework. Materials were delivered electronically and the online system randomly assigned participants to condition. The study design is a 5 (condition) X 3 (posttest task) mixed model factorial.

2.2. Materials

2.2.1. Instructional material

The instructional material was a 1655-word tutorial on skeletal muscle that covered content required for the physiology course. The tutorial was assigned approximately two weeks before a course exam that tested this content. The tutorial was 23 pages; 21 pages contained one diagram, two pages contained two diagrams. All diagrams were in color and included captions and structure labels. Diagrams represent the same key structures and processes included in the corresponding text. A pilot test with these materials confirmed that students who study the text with the diagrams learn more than students who study the text without diagrams.

Each page of the electronically-delivered tutorial included response prompts consistent with assigned conditions and a textbox into which responses were typed. Hereafter, the combined instructional material, response prompts, and textboxes are referred to as the tutorial. Fig. 1 shows a sample page from the SE condition.

2.2.2. Experimental instructions

The course instructor delivered instructions to participants in all conditions through a video shown at the start of the materials and these instructions are considered part of the experimental manipulations for each condition. The instructor explained how to study the tutorial and respond to experimental prompts. At the end of the video, participants used a sample page from a text on the cardiovascular system to practice responding to experimental prompts. Participants could access a model response appropriate to their condition after completing their own answers. Participants in all conditions were told that prompts would be given on each page along with text boxes for typing the response.

Instructions for the DA, SE, and DA-SE conditions were derived from the same base script. This script overviewed the task of learning from biology textbooks, identified a strategy that could improve textbook learning, and explained how to use that strategy. The base script explicitly referenced diagrams in two locations. First, the opening line stated that textbooks use both text and diagrams to express important concepts and relationships between these concepts. Second, the instructor later stated that both text and diagrams contain important information. There was no other mention of diagrams in the base script. The base script was altered for each experimental condition, which resulted in minor differences in video length across conditions. These lengths in minutes and seconds were: DA = 1:53, SE = 1:47, DA-SE = 2:05.

DR and NT condition instructions were also developed from the same base script. The nature of these conditions lead to substantial variations, but neither script included the two references to diagrams described above. These participants were told that textbooks express important concepts on each page, many students do not pay attention to their textbooks, and they should carefully study their texts to understand how parts of systems fit together and how these systems work. The video lengths in these two conditions were: DR = 1:03, NT = 1:01.

2.2.2.1. Diagram awareness (DA). DA condition participants were told that diagrams and text-diagram relations are important, but many students do not pay attention to diagrams. Instructions explained that text and diagrams may contain different information. Participants were told they would use a goal-setting strategy

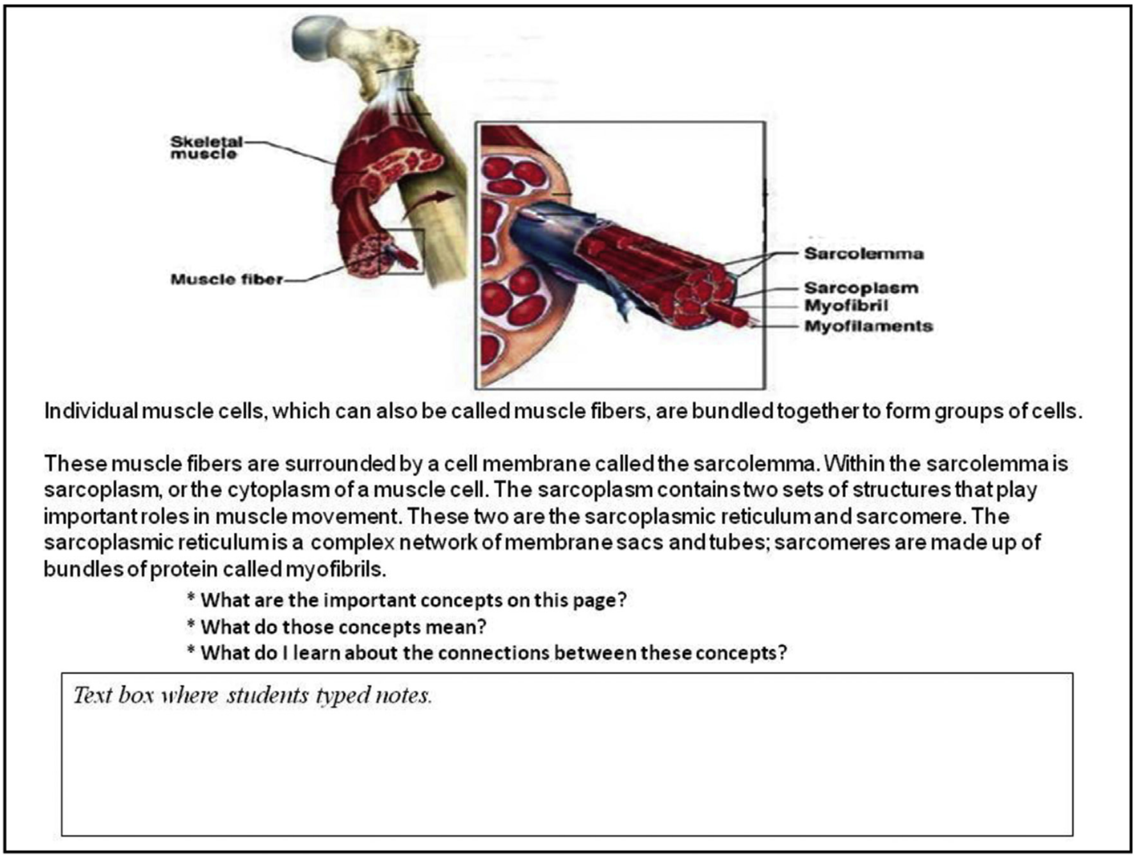

Fig. 1. Muscle tutorial screenshot from self-explanation (SE) condition.

to think about text and diagrams and that they would have to be aware of the text and diagrams to achieve this goal. The specific goal was to understand the relationships between text and diagrams on each page.

The response prompts in this condition were: “Pay attention to the text and diagrams on each page” and “Think about how they are related.”

2.2.2.2. Self-explanation (SE). Participants were told that many students do not use effective learning strategies when studying biology textbooks. Instructions explained that information presented on a textbook page can help them understand the parts of a system and how these parts work together. Participants were told they would use a self-explanation strategy to explain relationships between concepts on every page. Explanations should help them understand how the system works. Participants were told to generate explanations using their own words and that these explanations should fill in missing information.

The response prompts for this condition were: “What are the important concepts on this page?”, “What do those concepts mean?”, and “What do I learn about the connection between those concepts?”

2.2.2.3. Diagram awareness and self-explanation (DA-SE). Participants were told that diagrams and text-diagram relations are important, but many students do not pay attention to diagrams or use effective strategies to understand how text and diagrams are related. Instructions stated that explaining how these representations are related can help students understand the parts of the system and how the system works. Participants were told to use the self-explanation strategy to help them think about how text and diagrams are related. Participants were told to use the text and diagrams on each page to fill in missing information and generate explanations. Participants were told they would have to be aware of the text and diagrams on each page in order to generate self-explanations.

Prompts in this condition were: “What are the important concepts included in the text and diagrams on this page?”, “What do those concepts mean?”, and “What do I learn from the connection between the text and the diagram?”

2.2.2.4. Directed response (DR). Participants were told that students who carefully study their textbooks and think about how the parts of a system fit together or what causes a system to work, learn more than their peers. Instructions explained that each tutorial page would contain a question to help them pay attention to important concepts and relationships. Examples of DR prompts include: “How do the thick and thin filaments interact to cause a muscle cell to become shorter?” and “Describe how calcium changes the thin filament. Be sure to discuss all of the different proteins in the thin filament as part of your answer.” No DR prompts directly referenced diagrams, but three of the 21 did address appearances; e.g., “Describe how the shape of the ion channel changes when acetylcholine no longer binds to the ion channel.” These three prompts could be addressed using information from the verbal text.

2.2.2.5. Notetaking (NT). Participants were told that students who carefully study their texts, and think about how the parts of a system fit together or what causes a system to work, learn more than their peers. Participants were told to pay attention to the concepts and relationships on each page, and to take notes on everything studied. The prompt in this condition was: "Use the textbox below to type your notes."

2.2.3. Experimental measures

2.2.3.1. Prior knowledge pretest. A 20-item multiple-choice test measured prior biology knowledge. The test covered a range of biology topics; e.g., structures of the tooth, brain, and cells; the course of diabetes. No question was specific to the tutorial. Cronbach's alpha for this measure was low ($\alpha = 0.55$), which is likely due to the range of topics covered.

2.2.3.2. Diagram comprehension measure. A 10-item multiple-choice test assessing the ability to comprehend geosciences diagrams (Cromley et al., 2013) measured DCA. All test items include diagrams and verbal text ranging from only structure labels to explanatory captions. Cronbach's alpha was 0.74.

2.2.3.3. Posttest tasks. A 40-item multiple-choice test comprised the three posttest tasks. Each task is defined by the tutorial representation (text/diagram) that holds the tested information and the representations used in the question. The Appendix contains sample items. The Text-Text (T-T) posttest task includes 13 items testing content from the tutorial's verbal text. Both the question stem and multiple-choice answer options were given as verbal text. The Diagram (D-D) posttest includes 14 items that test information found within tutorial diagrams. Both question stems and choice options contained diagrams, although text sufficient to present the question was also included. The 13-item Text-Diagram (T-D) task assessed knowledge located across tutorial text and diagrams. For these questions, either the question stem *or* answer options were presented as text and the alternate portions of the item contained diagrams. Accordingly, T-D questions required an inference to connect text and diagrams.

All three posttest tasks included both recall and inferencing questions and questions were distributed throughout a single test. Alpha coefficients were: full test = 0.83, T-T = 0.68, D-D = 0.63, and T-D = 0.60. Allowing participants to complete study materials as homework rather than in a laboratory setting likely contributed to the low internal consistency of the three posttest tasks. Nonetheless, all alpha coefficients meet or exceed the value of 0.60, which is sufficient for research purposes (Evers, 2001).

2.3. Procedure

An experimenter visited the class to recruit participants, explain the nature of the research, and disclose the instructor's role in the research. Students were told that experimental material covered course-required content, but that consent was necessary to use to their data in research. Informed consent was provided at the time experimental materials were completed.

The DCA and prior knowledge measures were completed during experimental sessions held in campus computer labs. Students signed up for sessions through an online system. Each session began with an explanation of the study and measures were delivered by *Qualtrics* (Provo, UT). Students completed the measures at their own pace.

Participants completed all other aspects of this research as course homework. Students were told that they should complete the work individually and without consulting additional material, but compliance cannot be confirmed because materials were completed independently. Regardless, this procedure to supports the generalization of findings to applied settings.

Qualtrics delivered all materials. Participants received an email providing a Qualtrics link. Upon accessing the link, students gave informed consent and received the experimental instructions, the tutorial, and posttests. Although students could move backward in the system during study of the instructions and the tutorial, no materials could be accessed again once that portion was complete. Qualtrics randomly assigned participants to conditions and delivered materials consistent with this assignment. Participants completed the posttest immediately following the tutorial. Questions were delivered one at a time.

Materials were available for one week. No time limits were imposed, but all materials had to be completed in a single log in. Time-on-task data is uninterpretable, however, because participants could complete the task over multiple sittings by keeping the website open.

2.4. Manipulation check

Because participants completed the material independently, a manipulation check was included to ensure that participants attended to condition instructions and did not share instructions with classmates. A subsample of 10 participants from each condition was randomly selected for this manipulation check. All textbox entries from these 50 participants were coded for evidence of the six characteristics shown in Table 2. These categories were developed to mirror experimental manipulations so that condition differences demonstrate that learners made efforts to comply with instructions and response prompts. Of these categories, condition differences were not expected for total words, content words, and paraphrases. Similar scores on these categories would indicate that participants in all conditions showed comparable effort and task engagement. Participants in the three experimental conditions were expected to have higher scores on the remaining three categories. DA and DA-SE participants, for instance, should have the highest scores on the two diagram-related categories. Two raters, who were blind to condition assignment, scored all entries from 20% of the subsample. Agreement exceeded 85% for all categories. One rater coded the remaining entries.

3. Results

3.1. Descriptive statistics and manipulation check

Table 3 contains means and standard deviations for all measures. Two five-group Oneway ANOVAs showed that there were no significant differences across conditions on either DCA [F (4, 275) = 0.66, p = 0.62] or prior knowledge [F (4, 275) = 0.63, p = 0.65]. Table 4 contains correlations between these variables and the posttest tasks. DCA is included as a covariate in subsequent tests of research hypotheses. Prior knowledge is not considered further because this variable is not tied to research hypotheses and the reliability of these scores is poor.

A five-group Oneway MANOVA, with condition as the independent variable and scores on the text entry categories as the dependent variable, evaluated the manipulation check. These data did meet the assumption of multicollinearity, but violated the assumption of normality and homogeneity of variance-covariance matrices. Pillai's Trace was interpreted. Table 2 contains means and standard deviations for each coding category across conditions.

The condition effect was statistically significant, F (24, 172) = 2.24, $p < 0.002$, $\eta_p^2 = 0.24$. Follow up univariate analyses found no significant differences across conditions on either total words [F (4, 45) = 1.01, p = 0.41] or total content words [F (4,

Table 2
Manipulation Check Coding Categories with Means and Standard Deviations for Each Category across Conditions

Category	Definition; score range	SE	DA	DA-SE	DR	NT
Total Words	Total typed words; 0– unlimited	746.70 (465.12)	886.50 (387.34)	915.80 (572.20)	693.90 (157.84)	595.10 (408.32)
Content Words	Number of key concepts; 0 - 187	91.70 (47.26)	116.30 (33.40)	101.00 (51.18)	97.00 (14.64)	88.10 (54.14)
Paraphrases	<50% is verbatim from provided text; 0 - 23	18.30 (8.67)	21.90 (1.97)	18.90 (8.17)	22.40 (1.26)	12.30 (8.91)
Self-explanations	Elaborates/explains provided information; 0 - 23	6.40 (5.19)	9.10 (6.12)	9.70 (8.37)	6.50 (3.78)	0.70 (0.67)
Diagram References	Includes references to diagram content; 0 - 23	0.20 (0.42)	7.50 (6.70)	8.10 (7.98)	1.40 (1.26)	0.10 (0.32)
Diagram-referencing explanations	Explanation/elaboration includes diagram reference; 0 - 23	0.00 (0.0)	4.40 (3.92)	6.20 (6.63)	0.70 (1.16)	0.00 (0.00)

Table 3
Means and Standard Deviations for Prior Knowledge, DCA, and Posttest Tasks (adjusted) by Condition

	DA n = 58	SE n = 54	DA-SE n = 51	DR n = 50	NT n = 67
Prior Knowledge	15.14 (2.34)	15.00 (2.50)	14.80 (2.51)	15.32 (2.13)	15.42 (2.16)
DCA	6.07 (1.76)	6.02 (1.85)	6.39 (1.66)	5.86 (1.86)	5.97 (1.75)
T-T	75.96 (17.98)	78.89 (18.00)	72.48 (18.06)	74.26 (18.03)	72.70 (18.02)
D-D	67.34 (17.68)	59.36 (17.71)	58.69 (17.78)	59.63 (17.75)	52.35 (17.69)
T-D	62.04 (18.75)	58.72 (18.74)	59.23 (18.78)	57.40 (18.74)	52.56 (18.76)
Posttest total	68.45 (15.54)	65.68 (15.51)	63.47 (15.57)	63.76 (15.48)	59.20 (15.48)

Table 4
Correlations between Prior Knowledge, DCA, and Posttest Tasks

	Prior knowledge	DCA	T-T	D-D	T-D
Prior Knowledge	–	0.12*	0.30**	0.22**	0.27**
DCA		–	0.27**	0.24**	0.23**
T-T			–	0.61**	0.63**
D-D				–	0.64**
T-D					–

**p < 0.01.

45) = 0.66, p = 0.63]. There were significant differences across conditions for paraphrased entries [F (4, 45) = 3.59, p < 0.01, η_p^2 = 0.24], self-explanations [F(4, 45) = 4.25, p < 0.005, η_p^2 = 0.27], diagram references [F (4, 45) = 7.24, p < 0.001, η_p^2 = 0.39], and diagram-referencing explanations [F (4, 45) = 6.75, p < 0.001, η_p^2 = 0.38]. Follow-up comparisons revealed that NT condition participants had significantly fewer paraphrased entries and entries containing self-explanations than participants in all conditions. There were no other differences across conditions for either of these two characteristics. In addition, DA and DA-SE condition participants included significantly more diagram references and incorporated more diagram references in their explanations than participants in any other condition. There were no other differences across conditions for these categories. Altogether, these findings confirm that participants attended to condition instructions and that these instructions were not shared with classmates.

3.2. Research hypotheses

A 5 (condition) X 3 (posttest task) mixed model ANCOVA with posttest task as the repeated measure and DCA as the covariate tested the main research hypotheses. Table 3 shows the adjusted means for posttest scores across conditions. Data met the assumptions for the mixed model ANCOVA and follow up procedures including sphericity and univariate heterogeneity of variance assumptions. There were significant deviations from normality for all three posttests and the DCA variable, but no values of skewness exceeded (–)1. Statistically significant differences were evaluated at p = 0.05. The Tukey-Kramer test evaluates all follow-up comparisons. Table 1 provides a summary of the results from all tests of interaction effects. The remainder of this section reports the results of the 5 × 3 mixed model ANCOVA that pertain to predicted interaction and main effects. Subsequent sections present follow up analyses where significant results are found.

The results of this ANCOVA were only partially consistent with predictions. First, the three-way interaction predicted by the instructional fit hypothesis was not significant, F (8, 540) = 0.68, p = 0.71. Second, the hypothesis that DCA would interact with condition (H2) was not upheld [F (4, 270) = 0.75, p = 0.56] nor was the expected DCA by task interaction (H3) found [F (2, 540) = 0.37, p = 0.69]. However, the prediction that there would be a significant task by condition interaction (H1) was supported, F (8, 540) = 2.76, p = 0.005, η_p^2 = 0.04.

Research hypotheses associated with main effects (H4, H5, and H6) were also supported. There was a significant main effect of condition [F (4, 270) = 2.95, p < 0.001, η_p^2 = 0.04], task [F (2, 540) = 178.68, p < 0.001, η_p^2 = 0.40], and DCA [F (1, 270) = 16.50, p < 001, η_p^2 = 0.08].

Follow up comparisons further explored these significant interaction and main effects. Because the interaction qualifies interpretations of the main effects, the significant condition by task interaction is addressed first below. Following sections examine the main effects.

3.2.1. Condition by task interaction

The condition by task interaction was decomposed by three simple effects tests that examined the effects of condition on task scores separately for each of the three posttest tasks. Significant simple effects tests were followed by Tukey-Kramer post hoc comparisons. Predictions associated with these comparisons, Hypotheses 1a through 1c, are summarized in Table 1. There were 10 comparisons made in each set of post hoc tests; i.e., each condition was compared to every other condition. Given the exploratory nature of this research and the significant interaction of the omnibus test, the probability value for evaluating these tests was set at p = 0.05 and trends are reported at values of p = 0.20. Because of the number of total comparisons, the following section reports all comparisons that yielded a significant difference, but not all non-significant findings are explicitly addressed.

A five-group Oneway ANCOVA with DCA as the covariate and T-T scores as the dependent variable evaluated the first hypothesis of this set. The condition effect was significant, F (4, 274) = 2.92, p < 0.05, η_p^2 = 0.02. Tukey-Kramer comparisons revealed that participants in the SE condition had significantly higher scores than participants in the DA-SE and NT conditions. The difference between the scores of participants in the SE and DR conditions fell just short of the statistical cut-off for evaluating trends. There were no other differences between conditions.

A second five-group Oneway ANCOVA with DCA as the covariate tested for condition effects on D-D scores (H1b). This test also revealed a statistically significant difference, $F\ (4,\ 274) = 13.07$, $p < 0.001$, $\eta_p^2 = 0.09$. Tukey-Kramer tests revealed two main patterns across conditions. First, consistent with predictions, NT condition participants scored significantly lower than participants in all other conditions. Second, DA condition participants had significantly higher D-D posttest scores than participants in all other conditions. There were no significant differences between the D-D posttest scores of participants in the SE, DA-SE, or DR conditions.

The five-group Oneway ANCOVA with DCA as the covariate was also significant when T-D scores were the dependent variable (H1c), $F\,(4,\ 274) = 5.67$, $p < 0.001$, $\eta_p^2 = 0.04$. Post hoc comparisons were largely consistent with predictions. Participants in all three experimental conditions had higher scores than NT condition participants although there was only a trend in this direction for the comparison between participants in the DA-SE and NT conditions ($p = 0.10$). The difference between DA and DR condition participants fell just short of the cut-off. There was only a trend showing participants in the DR condition to have higher scores than NT condition participants. There were no differences between the T-D scores of SE, DA-SE, and DR participants.

In summary, the results of simple effects and post hoc tests were generally consistent with the expectation that the benefits of different response prompts vary according to the task used to assess learning. DA prompts had the greatest impact on task performance when tasks assessed knowledge gained from diagrams and text-diagram relations. On the verbal T-T task, however, only SE prompts were more effective than NT control prompts. Some findings were inconsistent with predictions shown in Table 1. First, although DA-SE condition participants were predicted to be amongst the highest scoring on all three tasks, these participants were the lowest scoring of the three experimental groups. In fact, these scores were significantly below those of SE condition participants on the T-T task and DA condition participants on the D-D task. Second, there was no advantage for DA condition participants relative to those in the NT condition on the T-T task.

3.2.2. *Main effects: condition, task, and DCA*

The 5 × 3 mixed model ANCOVA also tested for main effects predicted by Hypotheses 4, 5, and 6. As reported in Section 3.2, there were statistically significant differences associated with each of these main effects. The remainder of this section reports on the Tukey-Kramer post hoc comparisons that examined these effects further.

The significant main effect of condition was decomposed by comparing the total posttest scores of participants in each condition to every other condition. These 10 comparisons revealed that both DA and SE condition participants had significantly higher total scores than NT condition participants. Trends indicate that DA condition participants also had higher total posttest scores than participants in the DA-SE and DR conditions. There were no other significant differences. These findings provide partial support for H4. While SE and DA condition participants did have significantly higher posttest scores than NT condition participants, participants in the DA-SE condition scored below expectations.

The next main effect, the effect of posttest task, was also explored in follow-up comparisons. Here, scores on each posttest task were compared to scores on the other tasks. These three comparisons revealed that participants had significantly higher percentage scores on the T-T task compared to both the D-D and T-D tasks. There were no differences in the percentage scores of the D-D and T-D tasks. These findings confirm the hypothesis that participants would score higher on the more familiar T-T task (H5).

Hypothesis six predicted an association between DCA and task performance. This hypothesis was evaluated by calculating correlations between DCA and scores on each of the three posttest tasks. The resulting correlation coefficients are: T-T: $r = 0.27$, $p < 0.001$; D-D: $r = 0.24$, $p < 0.001$; T-D: $r = 0.27$, $p < 0.001$. These correlations indicate that DCA exerts a small but consistent effect on learning from multimedia material. The stability of this relationship across the three posttest tasks is consistent with the finding of no interaction.

4. Discussion

The purpose of this research was to test the effects of different response prompts on college students' learning from text and diagrams. Influenced by the instructional fit hypothesis (Nokes et al., 2011), we predicted that there would be an interaction between these prompt conditions, the type of posttest task, and learners' ability to comprehend diagrams. The expected three-way interaction was not found in this study nor was the individual difference variable DCA found to interact with either the condition or task variables. The hypothesized condition by task interaction was statistically significant as well as the main effects predicted for each of the condition, task, and DCA variables.

4.1. *Condition and task interactions*

4.1.1. *Self-explanation and diagram awareness prompts*

The effects of SE and DA prompts were consistent with expectations that the benefits of a response prompt are best revealed on tasks that are aligned with the cognitive operations stimulated by that prompt (Nokes et al., 2011). SE condition participants had an advantage on the verbal T-T task. DA condition participants had their greatest advantage when the task assessed diagram knowledge, but this position weakened when the task included the assessment of verbal knowledge.

These effects can be interpreted by considering how condition prompts affected learners' application of the cognitive operations of multimedia learning. The SE prompts in our study called for the generation of verbal self-explanations. These explanations may have stimulated the selection, organization, and integration of elements from the verbal text but SE prompts did not direct learners to apply these operations to diagrams. In the absence of this direction, learners may not incorporate diagram elements in explanations because multimedia study tends to be text driven (e.g., Mason et al., 2013). Consequently, SE condition participants were better prepared for an assessment of text knowledge than an assessment of knowledge derived from diagrams.

DA condition participants, by contrast, were told to attend to diagrams. To maximize the potential of multimedia material, a learner must select, organize, and integrate elements from these representations. But, these operations are only possible if learners attend to the diagrams. The pattern of cross-condition performances on the posttest tasks suggests that the DA condition manipulations did increase learners' attention to, and learning from, diagrams.

Findings from the manipulation check conducted in this study are consistent with this interpretation. First, DA and DA-SE condition participants included significantly more diagram references and diagram-referencing explanations in their typed responses than participants in any other condition. This verifies that DA prompts effectively increased learners' attention to diagrams. Second, there were no significant differences in the number of explanations that SE, DA, and DA-SE condition participants included in typed responses. These findings are consistent with previous research. On the one hand, that is, prompting participants to self-explain does increase the generation of explanations. In addition, however, learners generate higher-order inferences more frequently when studying diagrams in comparison to text (e.g., Ainsworth & Loizou, 2003). Thus, although it is somewhat surprising that DA condition participants generated slightly more of these inferences than participants in the SE condition, it is not surprising that these inferences were stimulated by attention to diagrams.

The results of the manipulation check also shed light on why DA prompts did not show a benefit on the T-T task despite stimulating self-explanation as frequently as SE condition participants. Participants in the DA condition included significantly more diagram references in their explanations than SE condition participants. This pattern suggests that DA condition participants did not attend as closely to the text when generating elaborative inferences as participants in the SE condition. On the whole, however, the results of the condition by task analyses indicate that telling learners to 'think about' text-diagram relations not only increases attention to diagrams but may also be an effective way of stimulating self-explanation during multimedia study.

4.1.2. Combined and directed response prompts

Although findings with respect to both the DA and SE conditions were generally consistent with predictions, DA-SE condition participants consistently scored below expectations. Participants in this condition were expected to do as well as SE condition participants on the T-T task and as well as DA condition participants on the two diagram-related tasks. Contrary to these predictions, DA-SE condition participants had significantly lower scores than SE condition participants on the T-T task and DA condition participants on the D-D task. There are several possible reasons for these findings. For instance, although DA-SE condition participants had to both attend to diagrams and self-explain, the instructions for this condition were only 12 and 18 s longer than those delivered to the DA and SE conditions. This effort to control for the length of instructions may have resulted in instructions that were less clear. Participants may also have been confused by the instructions to both attend to diagrams and text *and* to explain text-diagram relations. Evidence from the text entry data of DA condition participants indicates that the direction to 'think about' the relations between text and diagrams was sufficient to stimulate explanations. Adding the directive to 'explain' the relation may have interfered with learning.

The materials used may also have affected DA-SE condition participants. Diagrams depicted the same structures and processes that were described in the text and thus, there may have been no conceptual knowledge gaps between text and diagrams. That is, participants may not have needed one representation to guide interpretation of the other. Although learners do often benefit from the presence of diagrams that are similarly related to the text (e.g., Butcher, 2006), self-explanation prompts may not improve multimedia learning in the absence of conceptual knowledge gaps (Wylie & Chi, 2014). In short, adding self-explanation to diagram awareness may not facilitate learning with this type of material.

Although the expected advantage of combined DA-SE prompts over either prompt alone did not emerge, DA-SE condition participants did have significantly higher scores than NT condition participants on both the D-D and T-D tasks. Participants in this condition also included more explanations, diagram references, and diagram-referencing explanations in their text entries than did NT condition participants. DA-SE prompts then, may have fallen short of expectations, but these prompts were more effective than instructions to take notes.

Finally, the DR condition did prove to be a stringent comparison group. DR condition participants scored significantly below experimental conditions on only one of the possible nine comparisons. This finding is in line with the effects of adjunct question, i.e., content-related questions presented alongside text. Higher-order adjunct questions, such as the questions used in the DR condition, have positive effects on a range of learning outcomes (Hamaker, 1986). Regardless of these positive effects, we find the prompts tested in our experimental conditions to hold greater promise for multimedia learning than DR style prompts. First, the totality of the evidence in this study indicates that DA prompts are more effective than DR prompts. Second, students could learn to independently apply the DA and SE strategies in future contexts. By contrast, the DR prompts relied on a content-area expert to supply the questions. Students could be taught to use a self-questioning strategy in which they would generate their own DR-style prompts. Self-questioning, however, may not be as effective or efficient as DA or SE because self-questioning requires instruction and is affected by prior knowledge (Wong, 1985).

4.2. Diagram comprehension ability

Although DCA did not interact with either the condition or task variables, there was a significant main effect of this variable. Two explanations may account for the presence of a main effect without any interactions. First, one expectation would be that low DCA participants benefit the most from DA-SE prompts because these prompts both direct attention to diagrams and stimulate an effective strategy. Low DCA learners, that is, are those most likely to need both diagram awareness and strategy supports. As previously discussed, however, the DA-SE prompts were not as effective as expected and this ineffectiveness may have impacted our ability to detect the predicted interaction. In sum, lower DCA participants' inability to gain extra support from the combined prompts may have been due to a poorly designed experimental condition rather than a lack of need for, or an inability to take advantage of, additional support.

A second possibility is that high DCA participants are simply more effective learners than low DCA participants. In this case, high DCA participants perform better than low DCA participants on both the diagram comprehension measure and the posttest tasks because these students have generally better performance on such academic tasks. This interpretation suggests that DCA is associated with, but does not cause learning outcomes.

Nonetheless, the main effect of DCA demonstrates that the ability to make sense of diagrams does impact multimedia learning. Whether this relationship is causal or a by-product of general learning ability cannot be determined by the current data. Additional research testing the effects of DCA instruction on multimedia learning should explore this relationship further to determine the possible benefits of increasing learners' ability to comprehend diagrams.

4.3. Limitations

The results of this study did not fully support the instructional fit hypotheses because there were no statistically significant interactions involving the DCA individual difference variable. Although this finding suggests that participants with varying levels of DCA may not respond differently to different prompts, this finding does not necessarily disconfirm the hypothesis because this interaction could be found with other individual difference variables. Prior knowledge is one such variable. Though prior knowledge was assessed in this study, we were unable to pursue this possibility here because of the measure used to assess this variable. First, poor reliability of scores on this measure would call into question conclusions drawn from this assessment. Second, the measure assessed biology domain, rather than topic, knowledge. If prior knowledge affects how learners use response prompts, we would expect that the relevant knowledge would be held at the topic level. Future research should continue to explore relevant individual differences, including prior knowledge, before concluding that the instructional fit hypothesis is incorrect on this point.

In addition, the results of this study may have been affected by features of the study design such as the use of learning material that was tied to participants' coursework. These features, for example, may have enhanced participants' motivation to learn and the course connection allowed experimental materials to be assigned as homework. On one hand, these features support the generalizability of findings to similar academic settings. Confidence is gained, for example, that similar results would be obtained if these same manipulations were used in an actual course. On the other hand, this design meant the loss of experimental control and the inability to rule out certain alternative explanations for the findings. There are three main concerns raised by this point. First, because time on task data cannot be interpreted, we cannot determine if different prompting conditions led participants to spend significantly more time studying the material than participants in other conditions. Second, we cannot guarantee that participants followed the instructions to work independently and avoid discussing the experience with classmates. Third, although the reliability of posttest task scores were acceptable, the individual task values were low with this poor reliability contributing error variance in statistical analyses. It is likely that allowing participants to complete experimental materials as homework contributed to the low internal consistency.

Findings from the analysis of participants' text entries do address some of the concerns raised here. This manipulation check confirmed that participants' effort was equivalent across conditions; there were no cross-condition differences on the total number of words typed or the number of content words included. There were differences, however, on categories that one would expect to be affected by experimental manipulations; i.e., elaborative explanations, diagram references, and diagram-referencing explanations. On the whole, this pattern suggests that participants did attend to experimental manipulations and did not share this information with classmates.

There are two additional limitations that should be considered. First, the effect sizes for condition effects were small. These small effects are to be expected in a study emphasizing external validity, but they should be considered when making decisions about the practical significance of the results. Second, these findings cannot be generalized beyond the materials used in this study. As previously noted, for instance, the overlap of concepts and processes depicted in the diagrams and described in the text may have affected the efficacy of the DA-SE condition manipulations. The results of this study may also have been affected by other characteristics of the material such as the use of diagrams that were representational, static rather than animated, and relatively complex.

4.4. Conclusions

This study indicates that providing learners with instructions and response prompts is an effective method to support multimedia learning. In particular, the prompts tested here were developed to stimulate the cognitive operations of multimedia learning; namely, selection, organization, and integration. DA prompts achieved this by increasing attention to diagrams and text-diagram relations. SE prompts achieved this by stimulating a multimedia learning strategy. Results also provide partial support for the instructional fit hypothesis (Nokes et al., 2011). Collectively, this study shows that there is a relationship between the cognitive operations stimulated by particular response prompts and the tasks for which they are preparing learners.

These results, however, do not suggest one particular type of prompt that is most effective. Only SE prompts significantly improved performance on the measure of verbal knowledge relative to the NT control condition, but DA condition participants scored significantly higher than SE condition participants on the measure of diagram knowledge. While the combination of these two in the DA-SE condition were intended to provide learners with the advantages of both types of prompts, this additive effect was not found. Future research is needed to determine methods that can enhance performance on both verbal and non-verbal assessment tasks.

In summary, there are at least three additional lines of research concerning the instructional fit hypothesis in the context of multimedia learning that should be pursued. One line could further explore the effects of DCA on multimedia learning. Although this study found no interactions associated with this variable, the main effect raises questions about the causal relationship between DCA and multimedia learning. Second, this study highlights the need to include assessments of both verbal and nonverbal knowledge when testing manipulations intended to affect multimedia learning. Our results suggest that a failure to include assessments of nonverbal knowledge may not provide a complete picture of multimedia learning. Finally, additional research is needed to test the generalizability of these findings to other types of multimedia material. Perhaps, for example, materials in which there are greater gaps between the content described in text and that depicted in diagrams would show different patterns of outcomes.

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Appendix. Sample posttest items

Text-Text Items

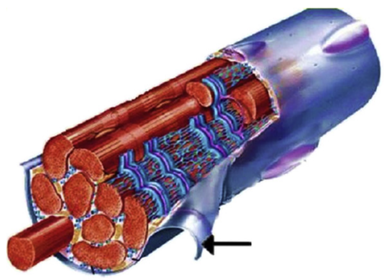
The list below contains a sequence of processes. From the options provided, select the process that belongs in the missing slot.

1. Energy is released when ATP is transformed to ADP
2. Myosin heads bend back
3. ____________________________
4. Myosin heads pull thin filament

a. *Myosin heads are released from active sites*
b. *Myosin heads attach to active sites on G actin*
c. *Myosin heads are released from thin filament*
d. *Myosin heads separate from troponin*

Diagram- Diagram Items

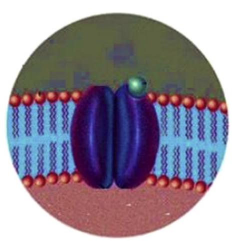
Please choose the correct label for the structure of the muscle fiber indicated on the image below:



a. myofibrils
b. myofilaments
c. sarcolemma
d. sarcoplasm

Text-Diagram Items

What is happening in the photo below?



a. Ach is binding to the receptor
b. Action potentials arrive at the synaptic knob
c. Calcium ions diffusing at the synaptic knob
d. End Plate Potential is reached

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