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ABSTRACT

Learner-generated drawing is an effective strategy that can be taught to support learning in Science (Ainsworth, Prain & Tytler, 2011; Van Meter & Garner, 2005). This study examined the effectiveness of drawing strategies for undergraduate students reading a tutorial about the processes of muscle contraction and relaxation. Undergraduates (n=341) were randomly assigned to one of four experimental conditions: control (read only), listing only, drawing only, or listing-drawing. Control participants only read the tutorial without any specific instruction. Listing only participants made a set of lists after reading the tutorial, whereas drawing only participants generated drawings after reading. Listing-drawing participants made a set of lists before drawing construction. Dependent measures included 24 multiple-choice items (11 verbal, 13 visual). A 4 group mixed model with verbal and visual posttest items as the repeated measure revealed a significant interaction between condition and posttest item type. Significant correlations were found between the number of key structures and processes included in participants’ drawings and the two posttest scores, verbal and visual.

Keywords: learner-generated drawing, drawing strategy, strategy instruction
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ACKNOWLEDGEMENT

To my adviser, Dr. Peggy Van Meter
Chapter 1

Introduction

The overall purpose of this study is to examine the effectiveness of learner-generated drawing as a strategy for learning from science text. This study is conducted to further explore differences in learning outcomes due to the strategy instruction effect among undergraduate students. This study aims to test if listing can improve effectiveness in the completion of a drawing task.

A body of educational research has examined the effectiveness of learner-generated drawings and found positive effects in the comprehension of expository texts (Leopold & Leutner, 2012; Mason, Lowe & Tornatora, 2013; Van Meter, 2001; Wang, Yang, Tasi & Chan, 2013; Zhang & Linn, 2011). Learner-generated drawings refer to any representational drawings that are created by students for the purpose of meeting certain learning objectives (Van Meter & Garner, 2005). Learner-generated drawings are regarded as key elements to text comprehension, as they assist to foster descriptive interpretations and coherent inferences presented in complex texts (Ainsworth, Prain & Tytler, 2011; Gobert & Clement, 1999).

Many studies discuss multiple roles that learner-generated drawing serve in learning. For example, Ainsworth, Prain and Tytler’s study (2011) highlights several roles of learner-generated drawing as organizing, integrating, representing, and reasoning beyond surface-level understanding. Specifically, drawing allows learners to summarize, organize, and integrate information as well as reason about content (Ainsworth, Prain & Tytler, 2011). Drawing also prompts the use of other strategies such as summarizing, organizing and integrating, in a way to build more elaborated and differentiated knowledge structures across texts (Van Meter & Firetto, 2013). Drawing construction allows learners to look for informationally equivalent links
presented between textual and visual information (Ainsworth & Loizou, 2003; Zhang & Linn, 2011). When drawing serves as an aid to better organize textual information in the form of graphic language, it allows learners to externalize their way of thinking while integrating both verbally and visually represented information (Edens & Potter, 2003). Meanwhile, the process of navigating relational links across the verbal and visual representations strengthens text comprehension (Ainsworth, Galpin & Musgrove, 2007). As such, drawing involves constructive learning processes, which forces learners to actively engage in the process of selecting and organizing through the integration of verbal information with nonverbal depictions (Van Meter & Garner, 2005).

Drawing can be used as an effective strategy that mediates cognitive processes between text comprehension and posttest performance (Van Meter & Garner, 2005). Edens and Potter’s study (2003) shows that learners who created drawings had significantly higher comprehension scores measuring conceptual understanding of the law of conservation than those who completed written reports. When properly implemented and matched to learning tasks, drawing facilitates observational processes leading to the acquisition of content-specific knowledge, thus improves posttest performance (Van Meter & Garner, 2005). The process of drawing construction facilitates a deeper level of comprehension, as factual concepts are “integrated into a complex causal chain to build a rich mental model” (Gobert & Clement, 1999, p. 41). Since drawing construction entails generative processes, its use as a learning strategy facilitates the act of organization and integration necessary for text comprehension (Rich & Blake, 1994; Van Meter & Firetto, 2013). Moreover, requiring learners to generate explanatory drawings directs them to attend to and extract “less perceptually salient information in particular” (Mason, Lowe & Tornatora, 2013, p. 212). Through the process of mental model construction, learners make new
inferences based on the integration of new and existing knowledge (Edens & Potter, 2003; Ainsworth, Prain, Tytler, 2011). In doing so, referential links are formed through reasoning across verbal and visual representations, reaching beyond surface-level understanding (Zhang & Linn, 2011).

Despite wide acknowledgment of its impact on learning, there are inconsistent findings of the actual efficacy of learner-generated drawings (Van Meter, 2001). Leutner, Leopold and Sumfleth’s study (2009), for example, found that a picture-drawing strategy even decreased comprehension of the expository text describing dipole characteristics of water molecules, whereas mental image strategy alone increased text comprehension. Similarly, picture-generating strategy reduced the overall comprehension of the expository text explaining chemical processes of washing (Schwamborn, Thillmann, Opfermann & Leutner, 2011). Further, in Hall, Bailey, and Tilman’s study (1997), there were no significant differences in problem-solving posttest scores between two groups of students who generated their own illustrations and others who studied provided illustrations. Such inconsistencies in empirical evidence contradict research that shows additive text comprehension benefits of learner-generated drawing.

Both the accuracy of constructed drawing and the presence of provided support are two important factors that improve the effectiveness of learner-generated drawings (Van Meter & Garner, 2005). First, many studies argue that the overall accuracy of drawings plays a critical role in learning (Leopold & Leutner, 2012; Mason, Lowe & Tornatora, 2013; Schwamborn, Mayer, Thillmann, Leopold & Leutner, 2010; Van Meter & Garner, 2005). In Schwamborn and colleagues’ study (2010), participants who constructed high-accuracy drawings had higher retention and transfer scores than their counterparts who generated relatively low-accuracy
drawings. In particular, drawings with an accurate depiction of explanatory text contribute to significantly higher posttest scores when compared to the ones with inaccurate information (Edens & Potter, 2003). Hall, Bailey and Tilman (1997) found that an accurate visual depiction allows learners to build more coherent, referential connections across verbal and visual representations just like a provided visual. The accuracy of the drawing in part represents the quality of the processes in which learners are engaged, as reflected by their ability to recall, relate, apply, and transfer knowledge across contexts (Leopold & Leutner, 2012).

Secondly, additional support is required to maximize the effectiveness of learner-generated drawings (Van Meter & Garner, 2005). Many students often fail to recognize and execute necessary processes leading to the construction of high-accuracy drawings (Schwamborn et al., 2010). Thus, simply asking them to draw without any further instruction about how to accurately draw does not always have positive effects (Van Meter & Garner, 2005). When instructional support is provided, learners are more informed about the ways to effectively use their drawings as visual aids (Rich & Blake, 1994). In Van Meter’s study (2001), participants who received the most support, such as inspecting illustrations after drawing and verbally answering questions to direct comparison processes, had not just the highest drawing accuracy scores, but also higher free recall scores than control participants. When effectively used, drawings help learners to better organize and integrate key ideas across verbal texts and visual depictions (Van Meter & Garner, 2005).

Though the empirical evidence shows inconsistent effects of learner-generated drawings on learning, the significant relationships between the accuracy of the drawings and learning outcomes suggest that drawing efficacy could be improved with instructional support. In other words, drawing needs to be taught in order to maximize its effect as students are not inherently
informed about ideal ways to engage in drawing construction to best support learning. Additional support should direct learners to implement strategies in a way that makes drawing more explicit and accurate. In doing so, learners would attend more to important, content-specific information to be included in drawings in accordance with text. When drawings include more relevant, key ideas, they represent a more precise understanding of the content being understood (Van Meter & Firetto, 2013). Because learners often analyze and integrate information “in the course of their everyday thinking,” direct explanations instructing ways to approach a drawing task deliberately control their thought processes during the drawing construction (Alesandrini, 1981, p. 366). In order to generate accurate drawings, learners need to specify their understanding to “such a degree that a drawing can actually be produced” (Van Meter & Firetto, 2013, p. 259). This includes a coherent understanding of important factual, featural, structural and functional information described in a text. In doing this, “if one cannot identify and abstract critical elements and relations,” it is nearly impossible to construct a high-accuracy drawing (Van Meter & Firetto, 2013, p. 259). In line with this, the present study tests the benefits of adding listing instructions to the drawing strategy. Listing instructions ask participants to make a list of key concepts, including both structural and procedural (functions) information, described in texts.

**Cognitive Model of Drawing Construction**

The Cognitive Model of Drawing Construction (CMDC), revised and developed by Van Meter and Firetto (2013), is the main theoretical framework used to guide the design this study. The CMDC claims that drawing construction starts with inspecting instructional materials. Learners first detect surface information and linguistic features of verbal to-be-learned content. Then they semantically process the featural information and form a network of propositions in
accordance with structural elements and relations. The propositional network becomes a basis for a mental model, as learners use the network to determine “which structures to include in the mental model, what those structures look like, and how they should be related” (Van Meter & Firetto, 2013, p. 255). Referential connections are then made through the integration of relational understanding about how concepts are connected and operate together (Mayer, Steinhoff, Bower & Mars, 1995; Schnotz 2002). Through the mental model process, a perceptual image of the internal representation is structured and externalized. These processes can also be understood from the perspective of self-regulated learning that is “triggered by efforts to create an external visual display” (Van Meter & Firetto, 2013, p. 259). Because drawing construction is not seen as a simple linear sequence but is completed through the recursive cycle described in the CMDC, learners often move back and forth within the cycle through a form of self-monitoring and feedback generation (Van Meter & Firetto, 2013).

The CMDC framework claims that the provision of instructional support serves two roles, constraint and self-regulation functions (Van Meter & Firetto, 2013). One of the goals of instructional supports is to help learners generate more accurate visual depictions of a verbal text by constraining their attention only to necessary cognitive processes. In the absence of the instructions, learners tend to solely rely on their familiarity with featural or structural relations of instructional content in drawing construction. In this case, learners’ prior knowledge works to direct cognitive processes toward the generation of internal representations. In order to construct accurate drawings, learners first need to realize the importance of attending to relevant and key information presented across the text (Mason, Lowe & Tornatora, 2013). Thus, instructional support should direct learners’ attention to key ideas central to texts, and to incorporate propositional knowledge network necessary for drawing construction (Mason, Lowe &
The other role of the instructional support is to encourage learners’ self-regulatory processes, which guide learners to utilize necessary cognitive processes involved in drawing construction (Van Meter & Firetto, 2013). In the CMDC framework, provided supports facilitate self-regulatory processes such as defining a task, setting goals, planning, and applying tactics through the control of self-monitoring and evaluation. In other words, instructional support allows learners to better regulate their task-related behaviors in the completion of a drawing task. For example, the computer-based drawing toolbar used in Schwamborn and others’ study (2011) allows learners to generate a picture by dragging, dropping, and combining parts of the provided pictorial elements (e.g., water molecules) of a science text explaining the chemistry of washing. In this task, the drawing toolbar controls task-related behaviors related to drawing construction. In Alesandrini’s study (1981) analytic and holistic instructions were manipulated to examine whether one type of support is more effective in learning concepts of electrochemistry relevant to a battery. In the study, participants in non-control conditions were told to study the material either analytically by focusing on details or holistically by relating specifics to the overall concepts (Alesandrini, 1981). Regardless of the instruction type, both strategies control the ways learners approach the task, which shape the kinds of behaviors engaged in drawing construction.

When learners are self-regulated, they are voluntarily engaged in the cycle of self-reflection throughout different phases of learning (Winne & Perry, 2000). Metacognitive awareness and control play critical roles in the recursive cycle, and in particular, metacognitive monitoring triggers the generation of internal feedback. During monitoring and evaluating processes, learners develop and revise internal feedback based on their understanding of the
“discrepancies between a goal and a current state of a task” (Winne & Perry, 2000, p. 550). Meanwhile, they monitor their progress and revise as needed in response to the generated feedback. Through the monitoring and evaluating processes, learners take control of their own behavior and make decisions about how to appropriately utilize strategies aligning with goals and standards (Winne & Hadwin, 2008). In other words, successful self-regulated learners are more open to choosing the right strategy that best fits with task objectives (Winne & Perry, 2000).

The principles of self-regulation depicted in the CMDC show that learners could benefit from the strategic behaviors of defining task, goal setting, planning, applying tactics and feedback generation in drawing construction (Van Meter & Firetto, 2013; Winne & Hadwin, 2008). The two roles of supports, constraint and self-regulation functions, described in the CMDC thus claims the need for specific instructions in drawing construction, which enables learners to be more strategic in using the right tactic. Embedded in the CMDC framework, the aim of this study is to examine differences in learning outcomes when strategy instruction is used to help undergraduates studying the processes of muscle contraction and relaxation.

Though overall benefits of learner-generated drawing are supported, the effect of drawing is maximized when the drawing is accurately constructed (Van Meter & Garner, 2005). For this, instructional supports can improve the accuracy of drawings. In line with this, the present study is designed to test the effects of listing. The listing manipulation asks participants to make a list of every key concept including both structures and functions (processes) from the text. Both listing and listing-drawing participants were informed that the act of listing would serve as a way to make them better organizes important concepts. In addition, listing-drawing participants received an additional instruction, which is to include every key concept from the list in their
drawings. In doing so, the listing manipulation helps listing-drawing participants to not just select key structures and processes from the text, but also organize the ideas to be included in their drawings. In order to externalize the understanding of key concepts in the form of drawing, listing-drawing participants need to comprehend how the concepts are related together (Van Meter & Firetto, 2013). When they are self-regulated, this phase involves the cycle of monitoring and generating feedback (Winne & Perry, 2000). By including the key concepts from the list in the drawings, learners generate more explicit drawings, which better represent conceptually accurate information.

Again, the overall purpose of this paper is to further examine whether listing can improve the effectiveness of learner-generated drawings. The research questions of this study are 1) do participants who generate both listings and drawings have higher posttest scores than those in the other three conditions? (control, listing only and/or drawing only) 2) do participants who make a list have higher scores on the verbal posttest items than those who do not list? And 3) do participants who generate drawings have higher scores on the visual posttest items than those who do not generate drawings?

Research Hypotheses

A 4 group mixed model with verbal and visual items as the repeated measure tested the first two hypotheses. Pearson’s correlation tested the third hypothesis.

1. There will be an effect of condition on posttest items influenced by item type.
   a. Participants in the listing and listing-drawing conditions will have higher verbal posttest scores than those in the control and drawing conditions.
   b. Participants in the drawing and listing-drawing conditions will have higher visual posttest scores than those in the control and listing conditions.
2. There will be a difference in mean posttest scores by condition.

3. There will be significant correlations between the number of key concepts included in lists and drawings and posttest scores.
   
   a. There will be significant correlations between the number of structures and processes included in lists and verbal posttest scores.
   
   b. There will be significant correlations between the number of structures and processes included in drawings and visual posttest scores.
Methods

Participants

Three hundred forty-one undergraduate students enrolled in a large public university participated in this study. Participants were 223 females and 116 males; two participants did not indicate gender. Participants’ ages ranged from 18 to 29 and they were equally distributed across conditions. The study consisted of 68% Caucasian/Non-Hispanic White (n = 232), 17.3% Asian (n = 59), 7.9% Hispanic (n = 27), 4.7% African American (n = 16), and 2% others. Approximately 66.3% of the participants indicated their overall GPA as 3.20 or above. Participants’ undergraduate majors were diverse (146 Biology, 59 Science, 42 Pre-medicine, 4 Biochemistry, 91 others) and the majority of participants were in their first or second academic year (n = 247). Participants were recruited from an undergraduate introductory biology course. Participation was voluntary; those who completed the study session were given extra course credit. Written consent was collected at the start of experimental sessions, by means of signed informed consent forms.

Materials

Instructional Materials

A paper-based tutorial of 23 pages (1,655 words) about the human skeletal muscle system was used as the learning material for all four conditions. The tutorial describes the processes that lead to muscle contraction and relaxation, content which required participants to understand structural and functional relationships. The content and page order of the tutorial is the same for
all four conditions. The tutorial contained 25 diagrams; 23 pages contained 1 diagram and two pages contained two diagrams. The diagrams represent the same key structures and processes included in the text and each diagram included captions and structure labels. All pages were printed in color. For participants in the drawing and listing-drawing conditions, seven of the 25 diagrams were removed from the tutorial and replaced with a blank space and condition-specific instructions (e.g., draw a diagram of cross-bridge formation; draw a diagram of the ACH receptor and end plate potential). These seven pages were equally spaced throughout the tutorial for listing, drawing, and listing-drawing conditions. None of the seven removed diagrams came from pages with two diagrams. The Appendix contains one of the seven pages with condition-specific instructions.

**Prior Knowledge Pretest**

A 20-item multiple-choice pretest measured participants’ prior biology knowledge. The pretest covered a range of general biology topics; e.g., structures of human heart, tooth, brain, and body tissue; the course of diabetes; the body’s defense mechanism against bacteria. No question was specific to the content described in the tutorial. Cronbach’s alpha for this measure was .55.

**Posttest Tasks**

A 24-item multiple-choice test measured learning of the tutorial. The posttest is composed of two different types of questions, which are categorized as verbal and visual items. For 11 verbal items, both question stems and multiple-choice answer options were written in verbal text. For 13 visual items, all multiple-choice answer options included diagrams used in the tutorial. The posttest was mainly comprised of lower-level questions requiring basic understanding of the structural and functional information presented in the tutorial. Cronbach’s
alpha was .79.

**Coding Rubric**

A rubric was developed to quantify total numbers of structures and processes included in the listings and the drawings. The researchers of this study came to a consensus in determining what should count as key concepts separately for each of the seven designated pages with condition-specific instructions. The key concepts include important structural and functional information central to the content of muscle contraction and relaxation. Participants’ written lists and drawings were then scored by counting the total number of these structures and functions included in the lists and/or drawings on each of the seven pages.

**Experimental Instructions**

In the beginning of each session, the researchers emphasized the importance of reading the provided instructions and sample pages prior to studying the tutorials. A sample page from a text on the cardiovascular system was used as an example showing the ways to follow the condition-specific instructions. Both control and listing only participants received a sample page with the visual of a cardiovascular system along with a text describing the system. Listing only participants had an additional page followed by the sample page, which shows the ways to make a list of key concepts. Both drawing only and listing-drawing participants received a sample page with the text describing the cardiovascular system, without the visual. Drawing only participants had an additional page followed by the sample page, which shows the ways to make a drawing about the text. Listing-drawing participants also had an additional page followed by the sample page, which shows the ways to make a list and drawing of the text. The text content of the sample page was identical for all four conditions. The researchers gave all participants about 5 to 8 minutes to read the instructions specific to their assigned conditions, along with the
sample pages. The following instructions, manipulated for each condition, were provided:

**Control (Read only):** The strategy you will be using is the reading strategy. As text content gets more difficult and complex, students who put more efforts into reading the text carefully learn more than students who don’t put much effort into reading. While reading a text on each page of this tutorial, please make sure to carefully study the described text.

**Listing:** The strategy you will be using is the listing strategy. Students who make a list learn more than students who don’t make a list. After reading a text, you will make a list of every key concept included in the text on that page. Key concepts include both structures (things) and functions (processes).

**Drawing:** The strategy you will be using is the drawing strategy. This drawing should look like the kinds of diagrams you are used to seeing in your biology textbook. Students who make a drawing learn more than students who don’t make a drawing. After reading a text, you will make a drawing.

**Listing-Drawing:** The strategy you will be using is the drawing strategy. This drawing should look like the kinds of diagrams you are used to seeing in your biology textbook. Students who make a drawing learn more than students who don’t make a drawing. But, drawing works best when it includes all the important ideas. To make sure that your drawing includes all the key ideas, you will also make a list. After reading a text, you will make a list of every key concept included in the text on that page. Key concepts
include both structures (things) and functions (processes). Then, you will make a drawing. When you draw, make sure your drawing includes every key concept from the list.

**Procedure**

The researchers of this study visited an undergraduate-level biology class to recruit participants. Potential participants were told that experimental material covered course-required, to-be-learned content, but that their consent was mandatory to use their data for this research. Each participant signed up for an experimental session through an online system. All sessions were held in a campus auditorium, which could seat a maximum of 60 participants at one time. Informed consent for all measures was provided and collected at the beginning of each session. Participants were randomly assigned to one of the four conditions, control (read only), listing only, drawing only, or listing-drawing, depending on the rows in which they happened to sit.

Each session began with an introduction and an overview of the purpose of the study. Everyone was given the same amount of time because they did it together as a whole class. All participants first completed the prior knowledge test and then read the provided instructions and example pages that aligned with their conditions. Participants were reminded to exactly follow the specific instructions that they read and respond accordingly as indicated in the tutorial. They were allowed to go back and forth between pages of the tutorial. All participants independently worked throughout the session at their own pace. When finished studying the instructional materials, each participant turned in the tutorial packet and completed the 24-item posttest.
Chapter 3

Results

Participant’s mean pretest score was 68.9 (SD = 13.3). Means and standard deviations for multiple-choice pretest scores across conditions are shown in Table 1. There were no statistically significant differences among group means as determined by one-way ANOVA $F(3, 337) = 1.669, p = .173$. A 4 group mixed model with verbal and visual items as the repeated measure tested the first and second hypotheses. Data met the assumptions for the mixed model ANOVA. The assumption of sphericity was met for the analysis with only two levels of within-subject factors. There were no outliers in the data, as assessed by inspection of a boxplot for values greater than 1.5 box-lengths from the edge of the box. There were no significant deviations from normality for verbal and visual posttest scores. There was homogeneity of variances for visual posttest scores ($p = .745$), but not verbal posttest scores ($p = .003$), as assessed by Levene’s test for equality of variances. Because sample sizes were approximately equal across conditions, the 4 group mixed model ANOVA is robust to violations of this assumption. Means and standard deviations for multiple-choice posttest scores (with separate verbal and visual scores) across conditions are shown in Table 1.

Hypothesis 1 predicted a two-way interaction of the between-subject factor, condition, and the within-subject factor, item type. The two-way interaction between condition and item type was significant, $F(3, 337) = 2.984, p = .031, \eta^2_p = .03$. Thus, we found support for the hypothesis 1 that the effects of condition would not be uniform between two different posttest item types, verbal and visual.
Hypothesis 1a predicted that participants in the listing and listing-drawing conditions would have higher verbal posttest scores, whereas hypotheses 1b predicted that those in the drawing only and listing-drawing conditions would have higher visual posttest scores than the other conditions. The condition by item type interaction was decomposed by simple effects tests that examined the effects of condition on verbal and visual posttest scores. There was not a statistically significant simple main effect of condition in verbal posttest scores, $F(3, 337) = 2.392, p = .068, \eta^2_p = .021$. Though the simple main effect was not statistically significant, the effect attained small practical significance via partial eta squared. There was not a statistically significant simple main effect of condition in visual posttest scores, $F(3, 337) = 1.105, p = .347, \eta^2_p = .010$. Thus, we did not find support for hypotheses 1a and 1b.

Hypothesis 2 predicted a statistically significant difference across conditions on the verbal and visual posttest scores. The main effect of condition showed that there was not a statistically significant difference in mean posttest scores among conditions $F(3, 337) = 1.539, p = .204, \eta^2_p = .014$. Thus, we did not find support for the second hypothesis that the effects of

Table 1: Means and standard deviations, for pretest and posttest scores (verbal, visual) across conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Total Pretest</th>
<th>Verbal Posttest</th>
<th>Visual Posttest</th>
<th>Total Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>Control</td>
<td>87</td>
<td>70.6</td>
<td>13.6</td>
<td>69.7</td>
</tr>
<tr>
<td>List</td>
<td>83</td>
<td>68.9</td>
<td>12.5</td>
<td>72.4</td>
</tr>
<tr>
<td>Draw</td>
<td>85</td>
<td>66.3</td>
<td>14.4</td>
<td>66.3</td>
</tr>
<tr>
<td>List+Draw</td>
<td>86</td>
<td>69.7</td>
<td>12.3</td>
<td>74.5</td>
</tr>
<tr>
<td>Total (N)</td>
<td>341</td>
<td>68.9</td>
<td>13.3</td>
<td>70.7</td>
</tr>
</tbody>
</table>
conditions would not be uniform in the posttest scores. As shown in Figure 1, listing-drawing participants have higher mean posttest scores than the other three conditions, regardless of item type, verbal and visual. This pattern suggests that the participants who used both the listing and drawing strategies somewhat outperform their peers on the total posttest.

Figure 1: A two-way interaction of conditions (control, list only, draw only and list+draw) and item type (verbal, visual) in percent (%)

Pearson’s correlation tested strengths and directions of linear relationships between the number of key concepts in lists and drawings and posttest scores. Preliminary analyses showed that the relationships between all possible pairs of the two variables were linear without any outliers. Not all variables were normally distributed, as assessed by Shapiro-Wilk’s test ($p < .05$), however, Pearson’s correlation was used as group sample sizes were approximately equal. Means and standard deviations for number of structures and processes across conditions are shown in Table 2 and 3.
Hypothesis 3a predicted significant correlations between the number of structures and processes included in lists and verbal posttest scores. Listing only and listing-drawing participants were included in the analysis. As shown in Table 4, all correlations between the number of key structures and processes included in participants’ lists and their verbal and visual posttest scores were not statistically significant. Thus, we did not find support for the hypothesis 3a that there are significant correlations between the number of structures and processes included in lists and verbal posttest scores.

Table 2: Means and standard deviations, for number of structures and processes across conditions in lists

<table>
<thead>
<tr>
<th></th>
<th>List Structures</th>
<th>Draw Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>List only</td>
<td>37.5</td>
<td>8.0</td>
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<td>List + Draw</td>
<td>33.1</td>
<td>6.7</td>
</tr>
</tbody>
</table>

Table 3: Means and standard deviations, for number of structures and processes across conditions in drawings

<table>
<thead>
<tr>
<th></th>
<th>Draw Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
</tr>
<tr>
<td>Draw only</td>
<td>34.1</td>
</tr>
<tr>
<td>List + Draw</td>
<td>35.7</td>
</tr>
</tbody>
</table>

Hypothesis 3a predicted significant correlations between the number of structures and processes included in lists and verbal posttest scores. Listing only and listing-drawing participants were included in the analysis. As shown in Table 4, all correlations between the number of key structures and processes included in participants’ lists and their verbal and visual posttest scores were not statistically significant. Thus, we did not find support for the hypothesis 3a that there are significant correlations between the number of structures and processes included in lists and verbal posttest scores.
Table 4: Correlations between posttest scores and numbers of structures/processes included in lists

<table>
<thead>
<tr>
<th></th>
<th>Structures</th>
<th>Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posttest</td>
<td>n</td>
<td>r</td>
</tr>
<tr>
<td>Verbal</td>
<td>169</td>
<td>.038</td>
</tr>
<tr>
<td>Visual</td>
<td>169</td>
<td>.014</td>
</tr>
</tbody>
</table>

Table 5: Correlations between posttest scores and numbers of structures/processes included in drawings

<table>
<thead>
<tr>
<th></th>
<th>Structures</th>
<th>Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posttest</td>
<td>n</td>
<td>r</td>
</tr>
<tr>
<td>Verbal</td>
<td>171</td>
<td>.407**</td>
</tr>
<tr>
<td>Visual</td>
<td>171</td>
<td>.317**</td>
</tr>
</tbody>
</table>

Note. **. Correlation is significant at the 0.01 level (2-tailed).

Hypothesis 3b predicted significant correlations between the number of structures and processes included in drawings and visual posttest scores. Drawing only and listing-drawing participants were included in the analysis. As shown in Table 5, all correlations between the number of key structures and processes included in drawings and their verbal and visual posttest scores were significant at the 0.01 level. In particular, there is a significant, moderate positive correlation between the number of structures included in drawings and verbal scores, with the number of the structures explaining 16.6% of the variation in the verbal scores. There is also a significant, moderate positive correlation between the number of structures in drawings and visual scores, with the number of the structures explaining 10% of the variation in visual scores. Moreover, there is a significant, weak positive correlation between the number of processes in drawings and verbal, and visual posttest scores, with the number of the processes explaining
7.3% of the variation in the verbal scores, and 6.9% of the variation in the visual scores. Thus, we find support for the hypothesis 3b that there are significant correlations between the number of structures and processes included in drawings and visual posttest scores.
Chapter 4

Discussions

The purpose of this study is to examine the effectiveness of drawing strategies in learning from science text. Consistent with the hypothesis 1, the effects of conditions are not uniform between two different posttest item types, verbal and visual. As shown in Figure 1, the overall mean visual scores are lower than the verbal scores across all four conditions, control, listing only, drawing only and listing-drawing. Considering that the control participants were the only condition who received diagrams along with the text, this pattern shows that the inclusion of visuals does not necessarily make a performance difference between the posttest items with and without visuals. Several explanations may account for this finding. The control participants may have paid less attention to the visuals, which made them spend relatively less amount of time studying the visuals compare to the text. For this, Mayer (2005) argues that the text-heavy nature of learning materials often causes learners overlook the importance of visuals presented along with a text. Moreover, the lack of strategic understanding about how to study visuals in relation to a verbal text appears to weaken the relational understanding of the visual and textual information (Mason et al., 2013). Thus, when posttest items require a coordinated set of visuals and a text, the lack of visual understanding could leave conceptual knowledge gaps between the two types of representations (Mayer, 2005).

Hypothesis 1a predicted that participants in the listing and listing-drawing conditions would have higher verbal posttest scores than those in the control and drawing only conditions. Though a non-significant simple main effect was found, there is a small effect of condition on verbal scores. As shown in Figure 1, those in listing only condition performed better than the control condition on verbal items, and those in the drawing only condition performed worse than
the control condition on verbal items. Overall, participants in the listing only and listing-drawing conditions had higher mean verbal scores than the other two non-listing conditions, control and drawing only. This pattern suggests that though not statistically significant, listing strategy benefited to outperform in posttest items without visuals.

Hypothesis 1b predicted that participants in the drawing only and listing-drawing conditions will have higher visual posttest scores than those in the control and listing conditions. There was a non-significant simple main effect of condition on visual posttest scores. As shown in Figure 1, only listing-drawing participants had higher visual scores than two non-drawing conditions, control and listing only. Inconsistent with the hypothesis 1b, drawing only participants’ mean visual posttest score is approximately the same as that of control participants who did not use any strategy. This pattern reveals that drawing strategy alone did not contribute to increased performance on posttest items with visuals. However, when drawing is combined with listing strategy, participants had a highest mean posttest score regardless of item type.

In contrast to previous drawing studies, the present study did not find a strong support for the drawing effect, as participants in two drawing conditions did not outperform those in two non-drawing conditions. Particularly for drawing only participants, such inconsistent finding may be due to the lack of strategic understanding about what to do with generated drawings and how to use them in ways to best support learning (VanMeter & Garner, 2005). When listing-drawing participants made a list with important key concepts and included them in their drawings, they had the highest mean posttest score of the four conditions, regardless of the posttest item type. This pattern reveals the way in which listing strategy works as an effective support for drawing as only the participants who use not just drawing strategy alone but the combined strategy of listing-drawing benefit the most. In sum, the listing strategy served a role in promoting
appropriate cognitive processes necessary to maximize the effect of drawing (Schwamborn et al., 2011, p. 90).

Hypothesis 3a predicted significant correlations between the number of structures and processes included in lists and verbal posttest scores. As shown in Table 4, all correlations between the number of key structures and processes included in participants’ lists and their verbal, visual posttest scores were not statistically significant. This reveals that the number of structures and processes included in the lists is not strongly related to verbal and visual posttest scores, respectively. In other words, just asking participants to include key structural and functional concepts in their lists might not necessarily impact posttest performance when they have a difficulty understanding what should count as “important” versus “not important” concepts.

Hypothesis 3b predicted significant correlations between the number of structures and processes included in drawings and visual posttest scores. As predicted, there is a moderate positive correlation of the number of structures included in drawings and their visual scores. This reveals that the participants who included more structural concepts in their drawings had higher visual posttest scores. More interestingly, however, the strongest correlation is found between the structural and procedural concepts included in the drawings and the verbal posttest scores. This finding shows that if participants include many numbers of structural or functional information in their drawings, they are more likely to have higher visual posttest scores.
Chapter 5
Limitations and Directions for Future Research

This study has some limitations that should be investigated in future research. First, researchers of this study did not verbally instruct each strategy, rather, all participants individually read provided instructions designed for each condition before studying the tutorial. Even though participants spent approximately 5 to 8 minutes reviewing the instructions and example pages, some participants may have paid less attention to the detailed instructions about what to do with the strategy. A second potential limitation of this study is that learning performance was tested only immediately after reading the tutorial. This might not represent a real classroom context where students are tested days and weeks after studying the material. Thus, it is worth exploring whether participants’ learning outcomes differs when they are measured by not just immediate but delayed posttest tasks.

In sum, the findings imply that informing learners to attend to visuals and drawings as much as verbal information is critical in acquiring more coherent text comprehension. Moreover, simply telling learners to list key information did not appear to strengthen text-visual relations, but when including the lists in their drawings, the drawing effect is maximized. In other words, only when listing strategy is supported by drawing strategy, participants had benefitted the most. Thus, teaching learners ways to extract and integrate visually presented information (from visuals and drawings) in combination with a text could serve as a more effective way of learning (Mason et al., 2013).
Appendix

Sample Posttest Items (visual, verbal)

1. What is happening in the diagram 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

3. Muscle fibers are surrounded by ________________.
   A) myofilaments  
   B) sarcolemma  
   C) synaptic vesicles  
   D) thick filaments

4. When the brain sends a signal to relax, ________________.
   A) calcium ions are released  
   B) the sarcomeres return to their original length  
   C) action potentials are sent to the motor neurons  
   D) t tubules retract

5. Energy needed for muscle contraction is provided by ______.
   A) ATP (adenosine triphosphate)  
   B) ADP (adenosine diphosphate)  
   C) ACh (acetylcholine)  
   D) AChE (acetylcholinesterase)

6. During a power stroke, ________________.
   A) the muscle is shortened  
   B) AChE dissolves ACh (acetylcholine)  
   C) a cross-bridge is broken  
   D) pumps pull calcium (Ca+) ions out of the sarcoplasm
Bibliography


Mason, L., Tornatora, M. C., & Pluchino, P. (2013). Do fourth graders integrate text and


