Learners' Use of Various Types of Representations during Self-Regulated Learning and Externally-Regulated Learning Episodes

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Abstract. This study empirically examines students' use of various representations (text-only, text and diagram, videos, and externally constructed representations) while learning about a complex science topic using hypermedia. Eighty-two undergraduate students were randomly assigned to one of two tutoring conditions: self-regulated learning (SRL) or externally-regulated learning (ERL). Participants in the self-regulated learning condition used a commercially-based hypermedia environment to learn about the circulatory system on their own, while participants in the externally-regulated learning condition also used the hypermedia environment, but were given prompts and feedback from a human tutor during the session to facilitate their self-regulatory behavior. Each participant's interactions with the hypermedia environment were video-recorded and were used to investigate any differences between the SRL and ERL groups' use of types of representations. Results from process data (think-aloud) indicate that students in the ERL condition spent significantly more time producing externally constructed representations, i.e. their own drawings or notes on the material, than students in the SRL condition. Students in the SRL condition spent significantly more time reading text-only than students in the ERL condition. Correlational analyses indicate that students who spent more time reading text-only scored lower on posttest measures of learning and those who spent more time constructing external representations scored higher on measures of learning. Implications for the design of a computer-based learning environment intended to foster students' effective integration of multiple representations during learning with hypermedia are discussed.

Keywords: Self-regulated learning, hypermedia, human tutoring, multiple representations, computer-based learning environments

Introduction

Students often learn about complex science topics using multimedia and hypermedia, which involve various sources of information, including diagrammatic representations, textual representations, formulaic representations, and animations or videos. These learners usually have the opportunity not only to view these various forms of representations, but also to construct their own pictorial or textual interpretations of the information conveyed in learning environments through externally constructed representations (i.e. drawing and taking notes). The role these different representations play in the learning process has been theorized and studied by various scientists in past years [1,2,3,4,5]. In addition, models on the way in which these multiple external representations are integrated by the learner to form internal representations have been developed, including Mayer's [6] Cognitive Theory of Multimedia Learning (CTML) and Schnotz's [7] Integrated Model of Text and Picture Comprehension (ITPC), which have both been informed by Baddeley's working memory theory [8], Paivio's dual coding theory [9], and Chandler and Sweller's [10] cognitive load theory.

In order for learners to achieve the potential learning outcomes while learning using hypermedia and multimedia, they must translate between various sources of information, including diagrams, text, and videos with narration. Although it has been assumed that multiple representations of information will always provide students with greater opportunity to realize this potential, previous research has shown, that, in fact, students do not always perform better when using text and diagrams [11,12,13]. In an attempt to explain why certain properties of multiple representations lead to greater learning outcomes, Mayer [6] and Schnotz [7] developed models of the way students integrate information from multiple representations and sensory channels into internal representations and mental models.

1. Theoretical Models of Learning with Multimedia

Both Mayer [6] and Schnotz [7] developed their models with three assumptions. The first assumption, based on Paivio's [9] dual coding theory, is that humans have visual channels and auditory channels, for processing visual and auditory information, respectively. The next assumption is that each channel of information has a limited capacity for processing, based on Baddeley's [8] working memory theory and Chandler & Sweller's [10] cognitive load theory. Finally, both models assume that humans, in actively attending to important information and organizing the selected information into internal representations, are active learners.

Mayer's [6] Cognitive Theory of Multimedia Learning (CTML) encompasses much more than simply the integration of multiple representations. However, we will only discuss this aspect of the theory. In Mayer's CTML, incoming information from a multimedia presentation first enters sensory memory according to its modality. For example, words can enter sensory memory either through the eyes (visual modality) or the ears (auditory modality), depending of the presentation mode. Pictures necessarily enter sensory memory through the eyes. Next, words and images from sensory memory that are deemed important are selected to move forward to working memory. Working memory operates at two distinct levels: 1) raw information entering WM from the senses, and 2) constructed knowledge in WM. The raw information in working memory is comprised of words selected from auditory sensory memory and outputted as a word sound base in verbal working memory and images selected from visual sensory memory and outputted as a visual image base in visual working memory. In order for these words and images to enter working memory, a learner must first attend to and select relevant images and words to proceed. After selected words and images enter working memory, the working memory system organizes the selected words into a verbal model and the selected images into a pictorial model. Finally, the verbal and pictorial internal representations are integrated with one another and with prior knowledge.

Schnotz's [7] Integrated Model of Text and Picture Comprehension (ITPC) is similar to Mayer's CTML, with interesting differences. First, in addition to text entering the auditory sensory register, in the ITPC, images, called sound images, also register in the auditory sensory memory. Next, both the visual and auditory sensory registries forward both words and images to visual and auditory working memory, respectively. In other words, the visual sensory registry can select words and images to proceed to visual working memory through the visual channel and the auditory sensory registry can select words and images to proceed to auditory working memory. Finally, verbal information in both visual working memory and auditory working memory proceeds to the propositional representation level in working memory and pictorial information in both visual and auditory working memory proceeds to the mental model level in working memory. Propositional representations and mental models in the ITPC are equivalent to the CTML's verbal model and pictorial model, respectively. Also, Schnotz refers to information from long term memory, which is integrated with the information from working memory, as cognitive schemata, rather than prior knowledge. The process of the eventual integration of the verbal and pictorial model into long-term memory is one which has received little elaboration in the theoretical models.

Ainsworth [1] argues that multiple representations play three major roles in learning. First, they play complementary roles, in supporting complementary processes and providing complementary information to the learner. Second, they constrain possible interpretations on the part of the learner by familiarity or by inherent properties. Finally, multiple representations aid learners in constructing a deeper understanding of material by supporting abstraction, by promoting generalization to novel situations, and by demonstrating relations among representations.

2. Previous Empirical Research on Multiple Representations

Various studies have examined how multiple external representations (presented and constructed) affect learning outcomes using different manipulations to text, diagrams, instructions, etc. Mayer, for example, has demonstrated that learners acquire more knowledge when learning from both text and diagrams, when the two representations are both informationally relevant [14] presented using temporal contiguity and spatial contiguity [15,16], non-redundant [14], and presented using both auditory and visual modalities [17]. Although Mayer has provided much evidence supporting these multimedia effects, known as the coherence effect, temporal and spatial contiguity effect, redundancy effect, and split-attention effect, respectively, these learning sessions were very short (average learning time from above-cited experiments was 120 seconds) and process data (think-aloud protocols) were not collected during the learning sessions to examine what learning activities the students engaged in while viewing the presentations. In addition, Mayer's studies involve pre-recorded presentations which do not give the learner any control over navigation. As of this writing, the role of integration of multiple representations in learning with hypermedia remains unclear.

3. Previous Research on Self-Regulated and Externally-Regulated Learning with Hypermedia

In order to investigate how students learn about complex science topics using hypermedia environments, Azevedo and colleagues [18,19,20] have been conducting experiments on students' use of self-regulated learning processes during learning sessions, by collecting think-aloud protocols on each learner. These experiments have demonstrated that learners acquire deeper understanding of material when they engage in active learning by setting goals for their learning sessions, monitoring their emerging understanding throughout the learning sessions, and enact effective learning strategies, such as coordination of informational sources, selection of new informational source, summarization, inference generation, hypothesizing, and knowledge elaboration [18,19,20]. They have also demonstrated that adaptive scaffolding [20,21], self-regulated learning training [18], and human tutoring [22,23] aid students in developing more sophisticated mental models at posttest. In regards to the role of multiple representations in self-regulated learning, one study [24] showed that students who spent less time on text-only learned more from pretest to posttest. This suggests that in order for students to gain a deeper understanding of complex science topics, they should visit different representations of the same material within a hypermedia environment.

Several of the learning activities Azevedo and colleagues investigate are relevant to learning with multiple representations. According to Mayer's [6] and Schnotz's [7] models of multimedia learning, in order for integration of information from multiple representations to occur, learners must actively integrate the incoming information with long-term memory, indicating that prior knowledge activation is an important activity. Also, students must be aware of the relevance of different representations in order to make appropriate choices about the content they should access (content evaluation). When text and diagram are spatially contiguous, students should engage in coordination of informational sources, by referencing the diagram when necessary while reading the accompanying text. If learners are constructing their own external representations of the material, they will be engaging in taking notes or drawing. Finally, if students are constructing more external representations, one would expect these students to read notes more often as well and possibly review the notes before the end of the learning session.

This paper investigates how access to a human tutor can affect the way learners use various representations and the amount of time these learners spend constructing their own external representations during learning about a complex science topic. The research questions for this study were: *1) How does access to a human tutor affect the amount of time learners spend in different representations of the circulatory system during learning with hypermedia?; and 2) Is there a relationship between amount of time in different representations and learning outcomes?*

4. Method

4.1 Participants.

Participants were 82 undergraduate non-biology majors from a large public mid-Atlantic university in the United States. The mean age of the participants was 21 years.

4.2. Paper and Pencil Materials.

Paper and pencil materials for the experiment included a participant informed consent form, participant demographic questionnaire, and identical circulatory system pretest and posttest. The circulatory system pretest and posttest were identical to those used by Azevedo and colleagues (e.g. [25]) and included a matching task, a labeling task, and a blood flow diagram task. In the matching task, participants were asked to match 13 circulatory system components to short definitions of the parts. In the labeling task, participants labeled 14 parts of the heart without the use of a word bank. In the blood flow diagram, participants were asked to fill in the order of components of the circulatory system in blood flow (beginning and ending with the superior and inferior vena cava), using a word bank.

4.3 Hypermedia Learning Environment (HLE).

During the learning sessions, all participants interacted with a commercially-based hypermedia learning environment to learn about the circulatory system. The main relevant articles, which were indicated to the participants during a training phase, were ‘circulatory system’, ‘blood’, and ‘heart’. These three articles contained 16,900 words, 18 sections, 107 hyperlinks, and 35 illustrations. All of the features of the system, including the search functions, hyperlinks, table of contents, multiple representations (e.g. pictures, videos, etc.) were available to the participants and they were allowed to navigate freely within the environment to any article or representation.

4.4. Procedure.

Each participant was tested individually in both conditions and participants in the ERL condition were tutored by an individual separate from the experimenter. Participants were randomly assigned to either the SRL (n = 41) or ERL condition (n = 41). Participants were given 20 minutes to complete the circulatory system pretest and immediately given the learning task by the experimenter. Participants in both the SRL group and the ERL group received the following instruction verbally from the experimenter and in writing on a sheet of paper that was available throughout the learning session:

> *You are being presented with a hypermedia learning environment, which contains textual information, static diagrams, and a digitized video clip of the circulatory system. We are trying to learn more about how students use hypermedia environments to learn about the circulatory system. Your task is to learn all you can about the circulatory system in 40 minutes. Make sure you learn about the different parts and their purpose, how they work both individually and together, and how they support the human body. We ask you to ‘think aloud’ continuously while you use the hypermedia environment to learn about the circulatory system. I’ll be here in case anything goes wrong with the computer or the equipment. Please remember that it is very important to say everything that you are thinking while you are working on this task.*

Participants in the ERL condition, in addition to receiving this instruction, had access to a human tutor who scaffolded student’s self-regulated learning by:
(1) prompting participants to activate their prior knowledge (PKA);
(2) prompting participants to create plans and goals for their learning and to monitor the progress they were making toward the goals, and

(3) prompting participants to deploy several key self-regulated learning strategies, including summarizing, coordination of informational sources, hypothesizing, drawing, and using mnemonics.

A tutoring script was used by the human tutor in the ERL condition to guide decision making in when prompts should be used and what kind of prompts to implement, given the current status of the learner. The script was created based on literature on human tutoring [26,27] and recent findings from empirical studies on SRL and hypermedia [18,19,21]. For more information about the tutoring script, please see [22].

4.5 Coding and scoring of product and process data.

This section describes the scoring procedure used for participants' pretests and posttests as well as the procedure used for coding participants' use of multiple representations.

Pretest and Posttest scoring procedure. The matching task was scored by giving either a 1 (for a correct match between the concept and its definition), or a 0 (for an incorrect match between concept and definition) on both pretest and posttest (range 0-13). The labeling task was scored by either giving a student a 1 (for a correctly labeled component of the heart), or a 0 (for an incorrectly labeled component of the heart) on both pretest and posttest (range 0-14). The blood flow diagram was scored by giving each student a 1 (for each correctly placed term) or a 0 (for each incorrectly placed term) on both pretest and posttest (range 0-8). The correct progression of the blood flow diagram was: 1) Right atrium, 2) right ventricle, 3) arteries/capillaries/veins or lungs, 4) lungs or arteries/capillaries/veins, 5) left atrium, 6) left ventricle, 7) arteries/capillaries/veins or body, and 8) body or arteries/capillaries/veins.

Use of multiple representations. Students' use of the various types of representations were coded by viewing the videos of the learners' interactions with the hypermedia environment. A time segment was coded as 'text-only' if the learner was reading text from any of the articles in the environment, with any diagrams appearing on the page occupying less than ten percent of the environment's real estate. Any time the student was reading text or inspecting a diagram or picture, while diagrams or pictures occupied ten percent or more of the real estate, was coded as 'text and diagram'. Any time the student was visiting the blood flow video/animation on either the 'heart' article or the 'circulatory system' article was coded as 'video', including times when the video was paused or being controlled by the learner. Finally, a time segment was coded as 'externally constructed representation' when the student was taking notes or drawing on paper provided by the experimenter.

5. Results

5.1 Question 1. How does access to a human tutor affect the amount of time learners spend in different representations of the circulatory system during learning with hypermedia? A one-way multivariate analysis of variance (MANOVA) was conducted to determine how access to a human tutor affected the amount of time learners spent in different representations of the circulatory system during learning with hypermedia. The condition had a significant effect on students' use of various types of representations, Wilks's $\Lambda = .58$, $F(4,77) = 14.09$, $p < .001$. The multivariate η^2 based on Wilks's Λ was strong, .42.

Analyses of variance (ANOVA) on each dependent variable were conducted as follow-up tests to the MANOVA. The ANOVA on text-only was significant, $F(1,80) = 38.88$, $p < .001$, $\eta^2 = .33$, and also the ANOVA revealed significance on externally constructed representation, $F(1, 80) = 32.00$, $p < .001$, $\eta^2 = .29$. Students in the SRL condition spent over twice as much time reading text-only, ($M = 9.25$ mins.), than students in the ERL condition, ($M = 4.36$ mins.). Students in the ERL condition spent over twice as much time constructing their own external representations, ($M = 15.11$ mins.), than students in the SRL condition, ($M = 7.35$ mins.). See Table 1 for means and standard deviations of each type of representation for each condition. There were no other significant differences between conditions.

Table 1. Time spent with each type of representation, by condition (in minutes).

Tutoring condition	Text-only *M* (SD)	Text+diagrams *M* (SD)	Video *M* (SD)	ECR *M* (SD)
Self-regulated learning (SRL)	9.25 (4.19)	20.08 (4.86)	2.54 (1.90)	7.35 (6.40)
Externally-regulated learning (ERL)	4.36 (2.78)	18.24 (4.86)	2.10 (0.89)	15.11 (6.01)

5.2 Question 2. Is there a relationship between amount of time in different representations and learning outcomes? Pearson's correlation coefficients were conducted to determine if there was a relationship between the amount of time in different representations and learning outcomes. The correlational analyses revealed significant, negative correlations between amount of time spent on text-only and matching learning gains, $r = -.28$, $p < .05$; labeling learning gains, $r = -.35$, $p < .01$; and blood flow learning gains, $r = -.45$, $p < .001$. The correlational analyses also revealed significant, positive correlations between time spent on externally constructed representations and labeling learning gains, $r = .28$, $p < .05$; and blood flow learning gains, $r = .34$, $p < .01$. See Table 2 for Pearson's correlations between time spent on each type of representation and each learning gain measure. There were no other significant correlations.

Table 2. Correlations between types of representations and learning gain measures.

Learning measure	Text-only *Pearson's R (sig.)*	Text+diagrams *Pearson's R (sig.)*	Video *Pearson's R (sig.)*	ECR *Pearson's R (sig.)*
Matching task	-.28 (.01)	.12 (.27)	.06 (.60)	.03 (.77)
Labeling task	-.35 (.001)	-.11 (.33)	.03 (.79)	.28 (.01)
Blood flow diagram	-.45 (.000)	-.08 (.46)	-.05 (.64)	.34 (.002)

6. Implications for the design of a computerized SRL tutor

The results from this study demonstrate that access to a human tutor does affect the way that students access different types of representations. Further, results indicate that learners who spend more time reading text (in this hypermedia environment) tend to score lower on learning outcomes and those who spend more time constructing their own external representations tend to score higher on learning measures. This seems to indicate that human tutors, as well computerized tutors designed to foster students' learning of complex science topics, should attempt to guide students to spend less time simply reading information and more time attempting to construct their own external representations of this information, by fostering the integration of text and diagrams and construction of external representations. Future studies of the effects of various types of learning scaffolds on students' use of multiple representations should include analyses on the various self-regulated learning activities that students are engaging in while using multiple representations. Researchers should attempt to converge findings on different manipulations to multiple representations that lead to greater learning outcomes [e.g. Mayer and colleagues' multimedia learning research, 14,15,16,17] with the literature on students' use of self-regulated learning processes [e.g. Azevedo and colleagues' work, 18,23].

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