Adolescents' Use of Multiple Representations of Information in Self-regulated and Externally-regulated Learning with Hypermedia

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Abstract

This study explored learners' utilization of multiple representations of information within a hypermedia learning environment during self-regulated and externally-regulated learning episodes. 135 middle school and high school participants were randomly assigned to either a self-regulated learning (SRL) condition, in which the learners attempted to use a hypermedia environment to learn about the circulatory system alone, or an externally-regulated learning (ERL) condition, in which learners attempted the same learning task, with access to a human tutor who facilitated their learning by administering prompts to engage in several adaptive self-regulated learning processes. Results indicate that learners in the ERL condition spent significantly more time constructing their own external representations of information (i.e. taking notes or drawing), and significantly less time reading text only, reading content with text and diagram, and watching the animation included in the hypermedia environment. In addition, correlations between the learning measures and time spent on these different types of representations indicate the learners who spent more time constructing external representations gained more from pretest to posttest, and those who spent more time in the remaining three types of representations gained less.

Keywords: Self-regulated learning, hypermedia, tutoring, multiple representations.

Introduction

Learning about complex science topics using hypermedia, multimedia, or even more traditional learning tools such as textbooks often requires coordination of multiple external representations (MERs) of information, including diagrammatic representations, textual representations, formulaic representations, and animations or videos. The eventual goal of manipulation of external representations is the formation of internal (mental) representations of knowledge which can then be used to solve problems, reason, understand, and engage with the world in a meaningful way. The role which both internal (mental) and external representations play in the learning process has been theorized and studied by various scientists in past years (Ainsworth, 1999; Bodemer & Faust, 2006; Cox, 1999; Seufert, 2003; Seufert, et al., 2007). In addition, models on the way in which these MERs are integrated by the learner to form internal representations have been developed, including Mayer's (2005) Cognitive Theory of Multimedia Learning (CTML) and Schnotz's (2005) Integrated Model of Text and Picture Comprehension (ITPC), which have both been informed by Baddeley's Working Memory (WM) theory (1986), Paivio's Dual Coding theory (1986), and Chandler and Sweller's (1991) Cognitive Load theory.

Although it has been assumed that MERs of information will always provide students with greater opportunity to realize their greatest potential for learning outcomes, previous research has shown, that, in fact, students do not always perform better when using text and diagrams (Goldman, 2003; Schnotz & Bannert, 2003; Van Meter, et al., 2007). In addition to MERs presented within various learning environments, students also usually have the opportunity to construct their own external representations of textual and pictorial information conveyed within learning environments, by drawing or taking notes. The role of drawing and note taking within learning episodes extends beyond simply offloading information which cannot be retained directly. In addition, previous research has shown that drawing can be an effective learning strategy for integrating textual and/or pictorial information into more accurate internal representations of various topics (for review, see Van Meter & Garner, 2005). In an attempt to explain why certain properties of MERs, and different experimental manipulations lead to greater learning outcomes, Mayer (2005) and Schnotz (2005) developed the two leading models of the way students integrate information from MERs and sensory channels into coherent internal representations.

Theoretical Models of Learning with Hypermedia

Both Mayer (2005) and Schnotz (2005) developed their models with three assumptions. The first assumption, based on Paivio's (1986) 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. Finally, both models assume that humans, actively attend to important information and organize the selected information into internal representations. In addition, Ainsworth (1999) has developed a taxonomy of the major roles MERs play in learning.

Mayer's (2005) CTML encompasses much more than simply the integration of multiple representations; however, we will only discuss this aspect of the theory. In this model, 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 WM. 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 WM is comprised of 1) words selected from auditory sensory memory and outputted as a word sound base in verbal WM and 2) images selected from visual sensory memory and outputted as a visual image base in visual WM. After words and images are attended to and selected for entrance into WM, the 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 (2005) ITPC is similar to Mayer's CTML. For a full discussion of his model, please see (Schnotz, 2005).

Previous Empirical Research on MERs

Various studies have examined how MERs (presented and constructed) affect learning outcomes using different manipulations of 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 (Mayer, et al., 2001), presented using temporal contiguity and spatial contiguity (Mayer & Anderson, 1991; Mayer, et al., 1995), non-redundant (Mayer, et al., 2001), and presented using both auditory and visual modalities (Mayer & Moreno, 1998). Although Mayer provides much evidence of 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 (e.g., think-aloud protocols) were not collected during the learning sessions to examine what learning processes the students engaged in while viewing the presentations. In addition, much of Mayer's research involves pre-recorded presentations which constrains learner navigation. Other researchers have empirically examined what methods can be used to facilitate learners' use of MERs (Kalyuga, et al., 1991; Huk & Steinke, 2007; Seufert & Brünken, 2006; Butcher, 2006; Schnotz & Bannert, 2003; Bodemer & Faust, 2006). According to Van Meter, et al.'s (2005) review of drawing as an effective learning strategy, in order for the activity of drawing to provide the greatest support to students while learning, the strategy itself should be facilitated in some manner. Due to the previous emphasis on more traditional multimedia presentations and textbook-type learning materials, as of this writing, the process of integration of multiple representations, and the effect of learning strategies such as drawing and taking notes on this process, in learning with hypermedia still remains unclear.

Previous Research on Self-Regulated and Externally-regulated Learning with Hypermedia

To more accurately reflect the dynamic and ongoing process of how students learn about complex science topics using hypermedia environments, Azevedo and colleagues (Azevedo, 2005; in press; Azevedo & Cromley, 2004; Azevedo, et al., 2004, 2005; Azevedo, et al., 2005; Azevedo & Witherspoon, in press) are investigating students' use of self-regulated learning processes during learning sessions, by analyzing process data in the form of think-aloud protocols. Our work demonstrates learners acquire deeper understanding of material when they engage in active learning by setting goals for learning sessions, monitoring 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 (Witherspoon, Azevedo, & Baker, 2007; Witherspoon, Azevedo, & D'Mello, 2008; Witherspoon, Azevedo, Greene, Moos, & Baker, 2007). Also, the research shows that learners who have access to a human tutor during learning gain more from pretest to posttest (Azevedo, et al., 2007; 2008). The results from the previous research on human tutoring conditions (externally-regulated learning) indicates that those learners who are scaffolded by an external agent (i.e. human tutor) not only demonstrate greater declarative knowledge learning gains and higher mental models at posttest, but also deploy SRL processes which have been shown to be associated with better learning outcomes in SRL with hypermedia (Azevedo, et al., 2007; 2008).

In regards to the role of multiple representations in self-regulated learning, one study (Cromley, Azevedo, & Olson, 2005) showed that students who spent less time on text-only learned more from pretest to posttest. Another study (Witherspoon, et al., 2007) supported this finding, and demonstrated that college students who spent more time actively constructing their own external representations (i.e. drawings or notes) performed better on posttest measures of learning and that learners in an externally-regulated learning condition tend to spend more time constructing these external representations. This suggests that in order for students to gain a deeper understanding of complex science topics, they should implement the drawing and note taking strategy, actively constructing external representations to support the construction of their own internal representations.

Goal of the Current Study

This paper investigates how access to a human tutor can impact how adolescent learners use various representations and the amount of time these learners spend constructing their own external representations during learning about a complex science topic with hypermedia. This investigation is part of a larger research project aimed at exploring how access to a human tutor can support learners' use of self-regulated learning processes and positively affect learning outcomes (Azevedo, et al., 2008). Results from the original study indicated that learners in the human tutoring condition (Externally-regulated learning; ERL) gained significantly more declarative knowledge from pretest to posttest, when compared to the self-regulated learning condition (SRL), and that a greater percentage of learners in the ERL condition were in higher mental model categories at posttest. The research questions for the current re-analysis of this data are: *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?*

Method

Participants

Participants were 135 middle school and high school students from two schools in a large mid-Atlantic city's suburb area. These participants received community service credits for participating. The mean age of the 73 middle school participants was 12 years (46 females) and the mean age of the 62 high school participants was 15 years (35 females). The participants all had little knowledge of the circulatory system, as evidenced by low mean pretest scores of 40.5%, 4.9%, and 15.5% for the multiple choice, labeling of the components of the heart, and blood flow tasks, respectively.

Paper and Pencil Materials

Paper and pencil materials included an identical circulatory system pretest and posttest. The circulatory system pretest and posttest were identical to those used by Azevedo and colleagues (2008) and included a matching task, a labeling task, and a blood flow diagram task. In the matching task, participants matched 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 filled 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.

Hypermedia Learning Environment (HLE)

During the learning session, all participants interacted with a commercially-based hypermedia learning environment to learn about the circulatory system. All participants had access to all of the features of the environment, including search functions, hyperlinks, table of contents, MERs (e.g. pictures, videos) and were free to navigate within the environment to any article or representation, although the three main relevant articles ('heart', 'blood', and 'circulatory system') were indicated to the participants during a training phase on the environment. These three articles contained, in total, 16,900 words, 18 sections, 107 hyperlinks, and 35 illustrations.

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* = 66) or ERL condition (*n* = 69). Participants were allotted 20 minutes to complete all of the circulatory system pretest measures and then 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, as well as in writing on a sheet of paper that was available throughout the learning session:

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.

Participants in the ERL condition, in addition to receiving this instruction, had access to a human tutor who scaffolded students' self-regulated learning by prompting participants to: (1) activate their prior knowledge; (2) create plans and goals for their learning and to monitor the progress they were making toward the goals; and (3) 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. This script was created based on previous literature on human tutoring (Chi, 1996; Graesser, et al., 1995) and recent empirical findings from studies on SRL and hypermedia (Azevedo, et al., 2004, 2005, 2007). For more information about the tutoring script, please see (Azevedo, et al., 2008, p. 53).

Coding and scoring of product and process data

This section describes the procedures used to score participants' pretests and posttests and code 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).

Use of multiple representations. Students' use of the various types of representations was coded by viewing the videos of the learners' interactions with the hypermedia environment. A segment of the video 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 'animation', 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. All of the time segments for each type of representation were summed for each individual participant to obtain a total number of seconds spent on each type of representation, which was in turn converted to minutes.

Results and Discussion

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?

An independent samples t-test verified that neither the SRL group (M = 39.98 mins) nor the ERL group (M = 39.99 mins) spent a significantly longer time within the learning environment, $t(133) = .007$, $p = .995$. 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' $\Lambda = .55$, $F(4,130) = 27.06$, $p < .001$. The multivariate η^2 based on Wilks' Λ was strong, .45.

Analyses of variance (ANOVA) on each dependent variable were conducted as follow-up tests to the MANOVA. Each of these follow-up tests revealed significance for each type of representation. Students in the SRL condition spent over twice as much time reading text-only (M = 9.58 mins) than students in the ERL condition (M = 4.36 mins), $F(1,133) = 37.39$, $p < .001$, $\eta^2 = .22$. The SRL students also spent more time inspecting text and diagrams (M = 20.95 mins) than the students in the ERL condition (M = 17.29 mins), $F(1,133) = 12.71$, $p < .05$, $\eta^2 = .09$. The ANOVA on animation representation was also significant, $F(1,133) = 19.70$, $p < .001$, $\eta^2 = .13$, revealing that the students in the SRL condition spent significantly more time watching the animation of the heart (M = 3.26 mins) than those in the ERL condition (M = 1.79 mins). Finally, the students in the ERL condition spent significantly more time constructing their own external representations (M = 16.23 mins) than the students in the SRL condition (M = 6.04 mins), $F(1,133) = 70.04$, $p < .001$, $\eta^2 = .35$. See Table 1 for estimated marginal means and standard errors for each type of representation by learning condition. As stated earlier, previous explorations of learners' self-regulated learning behavior have evidenced that learners who spend more time constructing their own external representations, and less time simply reading content, learn more from pretest to posttest (Cromley, et al., 2005; Witherspoon, et al., 2007). This active construction of one's own external representation appears to facilitate the construction of internal representations (cf. Van Meter, et al., 2005).

Table 1. Estimated Marginal Means for time spent with each type of representation, by condition (in minutes).

Type of representation	Learning condition	
	Self-regulated learning (SRL) *M* (SE)	Externally-regulated learning *M* (SE)
Text only	9.58 (.61)	4.36 (.60)
Text + diagrams	20.95 (.73)	17.29 (.72)
Animation	3.26 (.24)	1.79 (.23)
Externally-constructed representation	6.04 (.87)	16.23 (.85)

Question 2. Is there a relationship between amount of time in different representations and learning outcomes?

Pearson correlation coefficients were conducted to determine if there was a relationship between the amount of time spent in different representations and learning gains on the three learning measures administered. These analyses revealed negative correlations between time spent on each of the three types of presented external representations and learning gains. In order to correct for possible Type 1 errors, Bonferroni correction was used, resulting in a p-value threshold of .004 (.05/12). Time spent on text-only was significantly negatively correlated with gains on the matching task, $r = -.25$, $p < .004$, and on the labeling task, $r = -.20$, $p < .004$. In addition, time spent creating externally constructed representations was significantly positively correlated with both gains on the matching task, $r = .31$, $p < .001$, and the blood flow diagram, $r = .28$, $p < .004$. There were no other significant correlations as a result of these analyses. See Table 2 for Pearson correlations between time spent on each type of representation and each learning gain measure. Again, this is further evidence of the benefit of learners' active construction of their own external representations during self-regulated and externally-regulated learning episodes.

Table 2. Correlations between types of representations and learning gains on three measures.

	Learning measure		
Type of representation	Matching *Pearson's r (sig.)*	Labeling *Pearson's r (sig.)*	Blood flow *Pearson's r (sig.)*
Text-only	**-.25 (.004)**	**-.20 (.001)**	-.15 (.08)
Text+diagram	-.18 (.04)	.05 (.56)	-.18 (.03)
Animation	-.16 (.06)	-.15 (.08)	-.23 (.008)
Externally-constructed representation	**.31 (.000)**	.11 (.19)	**.28 (.001)**

Bold typeface indicates correlations which are significant at the .004 level.

Conclusions

This paper provides additional evidence that human tutors (as externally-regulating agents) influence students' use of multiple representations during learning about complex science topics with hypermedia environments. Adolescent learners who have access to a human tutor tend to spend less time passively reading text and inspecting diagrams and animations from the learning environment, and more time actively constructing their own external representations of the textual and pictorial information. In addition, these results mirror previous findings (Witherspoon, et al., 2007) that learners who spend more time constructing these external representations perform better on posttests tapping both declarative and conceptual knowledge of the complex science topic. These findings indicate that an externally-regulating agent (i.e., a human tutor or adaptive hypermedia system) should not only prompt the construction of learners' own external representations, but also facilitate this process during learning. An adaptive hypermedia system could incorporate such a facility in the interface, within which a learner could construct his or her own external representations of the content, under the guidance of an externally-regulating agent (e.g. animated pedagogical agent). Future research should investigate the applicability of these findings to learning environments involving animated pedagogical agents as external-regulators of SRL behavior.

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