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INTEGRATION SCAFFOLDING IN HYPERMEDIA LEARNING

by

Amy Marcelle Johnson

A Dissertation

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Doctor of Philosophy

Major: Psychology

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Abstract

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This dissertation project used 80 undergraduate students to examine the effectiveness of three forms of facilitation in hypermedia learning with text and diagrams about the human circulatory system: 1) signaling key terms, 2) prompted referencing of diagrammatic representations, and 3) integration scaffolding which provided facilitation in locating corresponding components within diagrams. These three experimental manipulations were compared to a control condition in which learners used the same hypermedia learning environment, without any facilitative feature in coordinating between text and diagrams. Two measures captured differences in learning: 1) a multiple choice pretest and posttest of declarative and conceptual knowledge and 2) a diagram interpretation task requiring learners to use diagrams to explain their understanding of the circulatory system. Eye-tracking measures and concurrent think-aloud protocols were collected during the 20-minute learning sessions to provide process measures of students' learning and a self-report cognitive load measure was administered immediately after the learning session. Results indicated that the integration scaffolding condition led to higher posttest scores on the multiple choice measure, but no significant differences were detected for the diagram interpretation task. Eye-tracking results demonstrated that the integration scaffolding condition had a higher number of and a higher total duration of fixations on relevant areas within the diagrams. The relevant areas represent diagrammatic representations corresponding to the textual referents within the accompanying text. Additionally, these learners spent a significantly larger proportion of their time inspecting diagrams looking at the relevant areas of the diagrams and a

significantly larger proportion of these learners' fixations were on relevant areas. Analyses of learners' self-regulated learning processes, based on concurrent think-aloud protocols, indicated that the integration scaffolding condition also generated more correct summarizations than the remaining groups. The self-report cognitive load measure failed to reveal any differences among the learning conditions. Taken together, these results provide support for models of text-picture integration (Mayer, 2005; Schnotz, 2005) and, to some extent, Cognitive Load Theory. Further, the experiment suggests that directing learners' attention to corresponding elements within text and diagrams can be an effective technique for facilitating the process of text-picture integration.

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Chapter 1

Introduction

Traditional and computer-based learning environments use multiple external representations (MERs) of information, including text, diagrams, animations, videos, simulations, graphs, and formulaic representations. It is often assumed that two is better than one when it comes to *external* representations promoting learning. However, research has shown this is not always the case (Canham & Hegarty, 2010; Chandler & Sweller, 1991; Goldman, 2003; Mayer & Gallini, 1990; Rouet, 2009; Schnotz & Bannert, 2003; Van Meter, Firetto, & Higley, 2007). Therefore, researchers attempt to determine what conditions lead to greater learning and more sophisticated *internal* representations with MERs and why these are helpful.

The ubiquity of learning environments with MERs motivates the need to discover optimal learning conditions for promoting the successful integration of textual and pictorial information. If learners fail to effectively integrate textual information with pictorial information when using learning environments with both types of external representations, then little learning can occur because the internal representations (i.e., memory codes, mental models) constructed by the learner will be inadequate. Furthermore, techniques capable of facilitating the integration process must be grounded upon theoretical and empirical bases that clarify the underlying cognitive processing that occurs during integration. Therefore, it is important to investigate the ways in which learners attain deep understanding through successful integration of text and diagrams and to fine-tune the methods to promote effective integration.

Researchers in cognitive psychology, educational psychology, education, and instructional design have already investigated for at least two decades how learners integrate the disparate sources of information, including MERs, to form coherent internal representations (Ayres, 2006; Chandler & Sweller, 1991; Kalyuga, Chandler, & Sweller, 1999; Kester, Kirschner, & van Merrienboer, 2005; Mayer, 2008; Mayer & Gallini, 1990; Moreno & Mayer, 1999; Scheiter, Gerjets, & Catrambone, 2006; Schnotz & Bannert, 2003; Seufert, Schutze, & Brunken, 2009). Theoretical models provide researchers with the scientific predictions necessary to develop successful manipulations and to track correlational relationships that naturally evolve while using MERs.

Empirical studies on text-picture integration have tested the efficacy of particular manipulations in promoting student learning, using various educational and professional domains (e.g., mathematics, engineering, biology, engineering, medicine) and diverse target populations (e.g., college, high school, middle school students).Computerized learning materials have typically been used in these investigations, as is the case in this dissertation. However, much of the previous research has been conducted within the context of multimedia learning, wherein learners have little or no control over the pace and sequence of instructional material (see Mayer, 2009). Comparatively little is known about how the principles derived from multimedia studies apply to non-linear, multi-representational hypermedia learning environments in which learners have to make decisions about which content to access, how to sequence the content, and which strategies to use to process the information (cf., Ainsworth, 2008; Hegarty, Narayanan, & Freitas, 2002; Tabbers, Martens, & van Merreinboer, 2001). I define multimedia as any learning environment (comprised of textual and pictorial information) that does not allow learners to determine their own sequence of instructional material. In contrast, hypermedia is any (multi-representational) learning environment which does allow the learner to choose his/her own sequence of instructional material to peruse. Some multimedia environments also do not permit learners self-pacing because the amount of time that the learner is exposed to each stimulus is predetermined (see Niederhauser, 2008). Nevertheless, learning environments which predefine the sequence of instruction, but allow self-pacing, are also defined here as multimedia.

This dissertation attempts to identify effective method(s) of facilitating the internal mental integration of verbal and pictorial information from external textual and pictorial representations when learners attempt to acquire sophisticated mental models of the human circulatory system. Mental models are defined broadly as individuals' internal representations of the operation of a physical system, such as the human circulatory system (Gentner & Stevens, 1983; Johnson-Laird, 1983). A mental model comprises information about relative spatial configurations of components within a system, the functions of the components, and relationships which exist between these components. The information contained within a mental model is used by the individual to *run* mental simulations of the operation of the system during the course of solving problems or making inferences concerning causes or effects of various states of the system (Hegarty, 1992). An individual's mental model may not be complete and accurate, but is actively constructed on the basis of the tasks and external information sources from the environment (Norman, 1983). Although the dissertation focuses on the processing of textual and pictorial representations, mental models are often also constructed or modified on the basis of other modalities and on physical interactions with real-world systems. In text-picture integration, learners' mental models are assumed to be constructed using incoming textual and pictorial information in the manner described by Mayer (2005) and Schnotz (2005).

The experiment conducted in this dissertation is principally aimed at exploring the potential enhancement of the use of diagrammatic[1] representations while learning with textual representations, but the project also investigates the impact of the learning conditions on learners' use of the text itself. As described in more detail later, earlier research on text-picture integration indicates that when verbal information is spatially distant from the pictorial information on the display, learning is negatively impacted because of a *split-attention effect*. Split-attention refers to the visual switching learners enact when presented with text and picture as spatially separated entities. According to the two major theoretical models of text and picture integration, in order for learners to mentally integrate verbal and pictorial information with some success, the verbal and pictorial information must be simultaneously active in working memory (Mayer, 2005; Schnotz, 2005). The split-attention effect is assumed to arise from the inability to retain both types of incoming information in working memory when the two representations are presented spatially distant from each other. Previous investigations have revealed that one way to alleviate the split-attention effect is by guiding attention to corresponding information within verbal and pictorial representations, using connecting lines (Huk & Steinke, 2007; Seufert & Brunken, 2006), color coding (Kalyuga et al., 1999; Ozcelik, Karakus, Kursun, & Cagiltay, 2009), color changes (Jamet, Gavota, & Quaireau, 2008),

[1] Diagrammatic representations (or diagrams), which are utilized in the proposed experiment, are a specific class of pictorial representations. Within diagrams, abstract representations of elements are used, rather than literal reproductions of the systems (as in photographs).

arrows (Moreno et al., 2010), or agent gestures (Moreno, Reisslein, & Ozogul, 2010).. The experiment in the current proposal considers one form of attention guidance between text and diagrammatic representations, highlighting pictorial information corresponding to the current textual representation.

The dissertation begins with a description of the theoretical background surrounding the broad topic of text and picture integration. Next, the issue of split-attention is presented and the various methods of overcoming this difficulty are discussed. The aim of the current project and the details concerning methodology are introduced next. The results of the dissertation are presented, followed by a discussion of the interpretations of these results and implications for theory, methodology, and education.

Theoretical Perspectives

The two dominant models of the integration of verbal and pictorial information are Mayer's (2005) Cognitive Theory of Multimedia Learning (CTML) and Schnotz's (2005) Integrated Model of Text and Picture Comprehension (ITPC). Both models hold that humans have separate channels for visual and auditory information (Paivio, 1986), each with a limited capacity for active cognitive processing (Baddeley, 1986; 2000; Sweller & Chandler, 1991). Also, both assume that learners actively select appropriate information, organize that information into coherent internal representations, and integrate verbal and pictorial information into long term memory. This section describes both theories because their assumptions form the bases of much of the research on learning with text and diagram.

Mayer's Cognitive Theory of Multimedia Learning. In Mayer's model (2005), incoming information from a multimedia presentation first enters sensory memory associated with a particular modality (Mayer, 2005; p. 37). Words can enter sensory memory either through the eyes (visual modality) or the ears (auditory modality), depending on the presentation mode. Pictures necessarily enter sensory memory through the eyes, a point which is disputed in Schnotz's model (2005). Next, those words and images from sensory memory that are deemed important by the learner, either consciously or unconsciously, are selected to enter working memory. The two processes related to this step within the model are *selecting relevant words* and *selecting relevant images.* Due to limited processing capacity, only those words and images that the learner attends to and selects for further processing are represented in working memory. The decision of which pieces of information are relevant to the task and necessary to understand the content is made by the central executive (Baddeley, 1986) that adopts metacognitive strategies. The central executive is responsible for allocating limited cognitive resources to selection, organization, and integration of important words and images.

Working memory (WM) 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 images selected from visual sensory memory. 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. The two processes related to this step in the model are *organizing selected words* and *organizing selected images.* Mayer suggests that multimedia learning involves construction of at least one of five types of mental models: process, comparison, generalization, enumeration, or classification. Process structures include explanations of how something works through cause-and-effect chains. Comparisons include lists of comparisons between two or more elements. Generalization structures define hierarchical relationships between a main idea and its supporting statements. Enumeration structures are simply comprised of lists of items. Classification structures define hierarchical relationships between superordinate and subordinate categories of elements. In the final step of text-picture integration, the verbal and pictorial internal representations are integrated with one another and with prior knowledge (*integrating words and images*). Prior knowledge relevant to the learning material must be activated (active in working memory) from long-term memory in order for the new information to be integrated into long-term memory. This final step of integration uses both verbal and visual working memory. Connections are made between elements and relationships in the two (i.e., verbal and visual) mental models and between those two models and prior knowledge. According to Mayer, the integration process is the most cognitively demanding stage in multimedia learning because it requires the learner to be aware of the underlying structure that represents the verbal and pictorial mental models.

Schnotz's Integrated Model of Text and Picture Comprehension. Both Mayer's and Schnotz's models assume dual-channel processing, limited capacity for both channels, and active construction of one's own understanding. However, Schnotz's model includes some important differences (Schnotz, 2005; p. 57). First, Schnotz establishes a clear distinction between representations that serve a descriptive function and those which serve a depictive function. Descriptive representations are those which include arbitrary symbols and thus have a semantic relationship to, but not an iconic similarity to, that which they represent. Depictive representations are those which are composed of icons and thus have some structural similarity to their referent. Schnotz thus distinguishes his model through two representational channels: a verbal or descriptive channel, and a pictorial or depictive channel. Information within the descriptive channel is processed using symbol processing whereas information in the depictive channel is processed using structure-mapping processes. Schnotz does not make the connection (as Mayer does) between sensory modality and representational format. For example, text does not necessarily have to be read through the eyes (e.g., blind readers). More commonly, descriptive and depictive information can be sensed through either the eyes or the ears, without the need for conversion to the alternate processing channel, as is required in Mayer's theory. Next, whereas Mayer suggests that printed text is shifted to the sound base in working memory through mental articulation of the visually-presented words, Schnotz proposes that words sensed through the eyes (and forwarded to visual working memory) proceed through the verbal channel to be organized into propositional representations. Additionally, Mayer claims that two mental models are constructed, a verbal mental model and a pictorial mental model, each of which can have one or more of the five knowledge structures introduced above. Schnotz claims that only one mental model is ever constructed, using internal mental representations from both the verbal and pictorial channel. This mental model is constructed on the basis of verbal information from auditive working memory, pictorial information from auditive working memory, propositional representations of the verbal information, and existing knowledge structures (cognitive schemata) within long-term memory.

Although both models supply broad depictions of cognitive processing elements (i.e., selection, organization, integration), unfortunately details are not provided about specific processes underlying the integration process. Schnotz does state that top-down processing guides the selection of relevant information to be organized into propositional representations and mental models. Because of the lack of clarity regarding the underlying processes influencing integration, testable hypotheses to support one model over the other are unavailable. Therefore, the purpose of the proposed experiment is not to provide evidence for one theory or the other. Instead, the assumptions from both models represent the bases for the development of the experimental conditions. The two critical assumptions underlying the experiment concern limited processing capacity within the two representational channels and the necessity to have verbal and pictorial information active simultaneously in working memory for integration to occur. The next section describes cognitive load theory, which addresses the limited capacity assumption directly.

Cognitive Load Theory. Many researchers exploring learning with text and diagrams endorse cognitive load theory (CLT; Paas, Renkl, & Sweller, 2003; Schnotz & Kurschner, 2007; Sweller, 1988; Sweller & Chandler, 1991; Sweller, Van Merrienboer, & Paas, 1998) to explain the findings regarding facilitation or inhibition effects from various experimental manipulations. Within Mayer's (2005) and Schnotz's (2005) models, the limited capacity assumption is compatible with CLT. According to CLT, every instructional (and non-instructional) condition places a certain burden (load) on working memory capacity. This load is subdivided into three distinct types: 1) intrinsic cognitive load; 2) extraneous cognitive load; and 3) germane cognitive load (germane load was added to the theoretical conceptualization in Sweller et al., 1998).

Intrinsic cognitive load can be thought of as the natural demand imposed by the material (e.g., physics, body systems) per se. According to Sweller et al. (1998), this kind of cognitive load depends on the amount of ‘element interactivity’ in a particular task. Some learning tasks, such as learning new symbols for objects or actions, have low element interactivity, and thus low intrinsic cognitive load. Other learning tasks, such as learning a mental model underlying a scientific process, have higher element interactivity, and thus require more elements to be held in working memory simultaneously, thereby increasing intrinsic cognitive load.

Extraneous cognitive load is that demand placed on the cognitive system as a result of the format of instruction, rather than the task itself. For example, including topically related but unimportant information diverts attention and cognitive resources from essential information, leading to greater extraneous load (Mayer, Heiser, & Lonn, 2001). In certain situations, extraneous load might enhance task performance, but will not promote learning (Chandler & Sweller, 1991; Sweller et al., 1998), thus it is considered not essential to learning and has the potential to detract from learning. Those who are responsible for instructional design have some amount of control over the amount of extraneous cognitive load imposed by their learning materials and should attempt to remove any unnecessary features or aspects of the learning environment that might increase this load, at the expense of relevant cognitive processing for the learning task. Often, though, the constraints of the learner’s cognitive system are not considered when designing instructional material, which frequently occurs when materials are constructed from intuitive design principles. These intuitions can lead to an overcrowded multimedia presentation, that overloads cognitive capacity (Mayer, 2005; Sweller et al., 1998). A common concern in the design of instructional materials is the possibility of creating situations that may cause split-attention (Chandler & Sweller, 1991; Cierniak, Scheiter, & Gerjets, 2009; Sweller, Chandler, Tierney, & Cooper, 1990) or the need to visually switch between one information source and another (e.g., text and diagram).

Germane cognitive load refers to the conscious effort made on the part of the learner to use appropriate cognitive processes in an attempt to construct internal representations of the material (Sweller et al., 1998). Although germane cognitive load can be increased in environments where extraneous cognitive load is lowered, one should not think of these two constructs as necessarily negatively correlated, since a learning environment can be low in both extraneous cognitive load *and* germane cognitive load. Sweller et al. (1998) emphasize that in addition to creating instructional materials that reduce extraneous cognitive load, designers should also attempt to include features which will direct learners to these appropriate cognitive processes during learning, thereby increasing germane cognitive load.

It is assumed and well supported that working memory capacity is limited, so the originators and proponents of CLT advocate reducing extraneous (that is, unessential) cognitive load that is imposed by instructional materials in order to free up resources for germane (that is, essential) processing to be maximized (Sweller et al., 1998). More recently, CLT has endorsed attempting not only to reduce extraneous cognitive load, but also to increase germane cognitive load, provided that the learner does not become overloaded (Sweller, 2005).

Theoretical perspectives summarized. The researchers offering these theoretical viewpoints have assisted in laying the groundwork for those interested in how learners process text and diagrams. Mayer (2005) and Schnotz (2005) have both described the macro-level cognitive processes involved in the integration of text and diagrams. Learners select information from textual representations and diagrammatic representations which they consider important through top-down processes (i.e., using prior domain knowledge) and bottom-up processes (i.e., selecting perceptually salient information). Next, they organize the information contained in textual representations into a verbal mental model and the information contained in pictorial representations into a pictorial mental model. Finally, the learners integrate the internal verbal and pictorial representations into a coherent mental model containing both descriptive (verbal) and depictive (pictorial) information.

Cognitive load theory (Paas et al., 2003; Schnotz & Kurschner, 2007; Sweller, 1988; Sweller & Chandler, 1991; Sweller et al., 1998) provides a theoretical framework underlying instructional design practices that takes into account the constraints of our cognitive system. Through consideration of how learning materials contribute to intrinsic, extraneous, and germane cognitive load, researchers have investigated the overall impact of these three types of load to learning outcomes, on-line cognitive processing, and subjective experiences of mental effort during task performance.

Split-Attention

Mayer and colleagues have developed several principles regarding the reduction of extraneous cognitive load in multimedia research (see Mayer, 2008, 2009). The split-attention effect, also referred to as the spatial contiguity effect, demonstrates that two sources of information (e.g., text and diagram) are processed better when presented in close spatial proximity to one another. This effect has been extremely well documented and replicated in many conditions (Austin, 2009; Chandler & Sweller, 1991; Cierniak et al., 2009; Mayer, Steinhoff, Bower, & Mars, 1995; Moreno & Mayer, 1999). Ginns (2006) reviewed research on the split-attention effect and temporal contiguity effect conducted up to 2004. In his review of 37 findings regarding split-attention, he found a mean effect size of 0.72 (Cohen's *d*). The traditional explanation for the split-attention effect is that split-source format leads to the necessity to retain verbal or pictorial information in working memory while searching the accompanying representation for relevant information. This necessity leads to an increase in extraneous cognitive load. Cierniak et al. (2009) tested this explanation (termed the extraneous load hypothesis) against the germane load hypothesis, which assumes that the decrease in extraneous cognitive load which occurs in integrated formats is also associated with an increase in germane processes. Thus, overall cognitive load should be the same for both formats, but learning will be greater for integrated formats. Results from their experiment supported the second explanation, as secondary task performance (Brunken, Steinbacher, Plass, & Leutner, 2002) was not hindered by split-source format, but subjective ratings of extraneous cognitive load were higher for the split-source when compared to the integrated format. Previous works also showed equivalent secondary task performance, but improved learning outcomes, for integrated formats when compared to split-source format (Kester, Kirschner, & van Merrienboer, 2005; Tabbers, Martens, & van Merrienboer, 2004). These results suggest that the benefit of integrated formats is not simply due to a decrease in extraneous load, but also is contributed to by an increase in germane processes related to building coherent internal representations .

Overall, results from research on split-attention indicate that the integration of textual information into the diagrammatic representation usually leads to greater learning outcomes and lower subjective ratings of extraneous cognitive load. An exception occurs when one representation is redundant with the other (Chandler & Sweller, 1991). In this situation, integrated format can, in fact, impede learning by forcing the learner to process an unnecessary source of information. Although these investigations have established that learning can be positively impacted through physical integration of verbal and pictorial information, when verbal information is lengthy or when the diagram used is extremely complicated, the physical integration of text and graphics might not always be possible. Accordingly, other researchers have investigated an alternative method of avoiding the negative effects of split-attention. Previous investigations that have examined attention guidance techniques to overcome split-attention are summarized next.

Attention Guidance

Attention guidance techniques involve directing learners to relevant (or corresponding) portions of pictorial representations during learning with text (Bartholome & Bromme, 2009; Berthold & Renkl, 2009; Huk & Steinke, 2007; Jamet et al., 2008; Jeung, Chandler, & Sweller, 1997; Kalguya et al., 1999; Seufert, 2003; Seufert & Brunken, 2006). Recall that theories concerning text-picture integration assume that for successful internal integration of verbal and pictorial information to occur, the necessary related verbal and pictorial information must be simultaneously active in working memory. When search processes for related information within two representations prolong the interval between reading about a component and inspecting visual information depicting the component within a diagram, the likelihood that the verbal and pictorial information are concurrently active in working memory is reduced.

By directing learners' attention to the corresponding elements within textual and pictorial representations, attention guidance techniques attempt to reduce the need for visual search in switches between verbal and pictorial representations, thereby alleviating the split-attention effect.

Kalyuga et al. (1999; Experiment 2) demonstrated a beneficial effect of a 'color-coding' technique, in which referents to the diagram in the text were highlighted in identical colors in both text and diagram. The authors found that learners in the color-coding group performed significantly better (compared to a control condition) on multiple choice measures of learning about function of the light circuit. They attribute the finding to the impact of the color-coding technique in reducing search time necessary for locating corresponding elements in text and diagram, resulting in reduction of extraneous cognitive load and ultimately freeing up cognitive resources for germane processing of the materials. However, it cannot be ascertained by this experimental design whether the beneficial effect of color coding is due to reduced search time, as hypothesized by the authors. It is also possible that the color coding served as a signaling device to the learners, indicating important key terms within the text and diagram, which led to the observed learning benefits (cf. Mautone & Mayer, 2001). A more recent investigation of the color coding effect, which utilized eye-tracking data during learning (Ozcelik et al., 2009), sheds more conclusive light on the hypothesized cause of the finding.

Ozcelik et al. (2009) offered two competing hypotheses for the demonstrated color-coding effect. First, the superiority of color-coded format could be due to learners' ability to locate corresponding information within the text and diagram more easily when corresponding elements are color-coded. This is the hypothesis originally proposed by

Kalyuga et al. (1999). If this hypothesis is valid, then search time for corresponding elements within diagram during reading should be shorter in the color-coded format than in the conventional format. The alternate hypothesis was that the color-coding effect could be driven through directing attention and elaboration to salient information, or color-coded information in text and diagrams. If this hypothesis is correct, then total fixation time on colored elements contained in text and diagrams would be expected to be higher in the color-coded format, compared to the conventional format. The authors used eye-tracking methodology to capture data about eye-fixations on text and diagram using the two presentation formats. Results replicated the beneficial impact of color-coding with a new domain, neurobiology. Eye-tracking results indicated that learners in the color-coding group had reduced search time in locating corresponding items between text and diagrams and also had longer average fixation time on the color-coded elements. Total fixation time on color-coded elements did not differ between the conditions. Therefore, the results supported the first hypothesis that color-coding facilitates learners' ability to locate corresponding elements between text and diagram. The results did not support the second hypothesis that the color-coding directs attention to the color-coded elements in general.

Seufert and Brunken (2006) conducted an experiment to investigate how hyperlinks between two forms of representations (e.g., text and pictorial representation) can aid learners in integrating the information from both. The experiment was a 2 (surface level help) x 2 (deep structure level help) design, resulting in four conditions: 1) no help, 2) surface level help only (SLH), 3) deep level help only (DLH), and both SLH and DLH. Surface level help consisted of marking the text with hyperlinks, which when clicked, would produce arrows pointing out corresponding components within the accompanying diagram. Deep level help consisted of verbal descriptions of how the two representations related to one another, which was placed directly below both representations. Results from the experiment demonstrated a significant interaction between the types of help, indicating that learners with surface level help, without deep level help, experienced higher levels of subjective (self-report) cognitive load during the learning task. However, there were no significant differences on learning outcome measures among any of the groups. The authors claim that the surface level help did not support the learners because the types of representations used in the study were more complex (i.e., two texts, two graphs, one table, and one chemical formula) than those used in a previous study that did reveal benefits for hyperlinking texts to diagrams (Brünken, Seufert, & Zander, 2005; reported in Seufert et al., 2007). It is difficult to determine, without access to the materials from both investigations, whether the disparate findings resulting from the two studies derive from the differing level of diagram complexity. Their results could be attributed to low power within their 2x2 between-subjects design (88 participants total).

The results from the studies on the impact of attention guidance factors provide somewhat unclear conclusions. It appears that in certain contexts, directing learners attention to corresponding elements in diagrammatic representations accompanying texts does lead to greater learning outcomes, but in others this factor does not have a beneficial impact (e.g., Seufert & Brunken, 2006). Results are still inconclusive regarding the potential beneficial impact of attention guidance within hypermedia learning, especially concerning which learning contexts are facilitated by this method of support and *why* this guidance sometimes leads to increased learning. Due to the conflicting evidence concerning the advantages of attention guidance methods, an experiment was devised to identify a successful attention guidance technique, referred to as integration scaffolding.

Goals of the Dissertation Experiment

The purpose of the dissertation experiment was to provide clarification on theoretical and empirical issues still outstanding in the literature on text-picture integration. First, various methods to alleviate the split-attention effect have been tested in separate experiments, but they have never been tested alongside one another in a direct comparison. This experiment afforded the opportunity to determine which form of assistance in coordinating spatially-separated text and diagram provides the greatest benefit, or if any of these methods actually diminish learning outcomes. Second, few experiments investigating attention guidance methods have employed eye-tracking methodology. This methodology has the potential to elucidate the process of text-picture integration and to test hypotheses concerning the underlying reasons behind demonstrated effects (e.g., reduced visual search time, added attention on salient elements). Third, the experiment included collection and analysis of self-regulated learning processes from concurrent think-aloud protocols. This method can assist in providing data on the specific individual cognitive processes used during the integration process. Fourth, although many multimedia principles, such as the split-attention (or spatial contiguity) effect, have been demonstrated in a multitude of studies, questions have been raised about the generalizability of such findings to hypermedia environments and even self-paced multimedia environments (Gerjets, Scheiter, Opfermann, Hesse, & Eysink, 2009; Tabbers, Martens, & van Merrienboer, 2004). Researchers in the field have doubts about extending the conclusions from multimedia studies to contexts in which learners have full control over the pace and sequence of instructional materials. This experiment was designed to resolve this outstanding issue because the environment involved hypermedia . In summary, the experiment uniquely contributes to research on text-picture integration through comparing multiple manipulations, employing eye-tracking and think-aloud methodology, and utilizing a hypermedia learning environment. In the following chapter, the details of the experiment are introduced, including the goals, research design, and methodology.

The specific aim of the project was to identify a beneficial method for facilitating the integration process when learning with textual (written) and pictorial information. One method of circumventing the split-attention effect and reducing extraneous load consists of prompting textual and pictorial coordination (*prompted referencing*). In prompted referencing, instructions to the learner to mentally relate text and diagram aim to promote the process of building connections between textual and pictorial representations (Bodemer & Faust, 2006). However, results from this set of experiments suggested that learners, especially those with low prior knowledge, demonstrate difficulty in successfully relating the two representations when prompted to do so. Mayer and colleagues have also reported evidence for the beneficial impact of *signaling* learners to attend to particular information (Harp & Mayer, 1998; Mautone & Mayer, 2001) within texts and diagrams.

In an earlier investigation, an attention guidance technique, called *integration scaffolding*, was used to make explicit the connections between text and diagrams. The results from this experiment indicated that the integration scaffolding technique led to greater learning outcomes (Witherspoon & Azevedo, 2008). However, it was unclear whether this effect was due to directing attention to relevant portions of the diagram, directing attention to relevant portions of the text (i.e., simply a *signaling* effect), or inducing the coordination of text and diagram (i.e., a *prompted referencing* effect). The reported experiment aimed to disambiguate which aspect of the integration scaffolding manipulation led to increased learning outcomes.

Given the results from previous research on attention guidance methods, it is still unclear which instructional design manipulation would prove most effective in reducing extraneous load and facilitating learning with text and diagrams. Furthermore, none of the previous work exploring *prompted referencing*, *integration scaffolding*, or *signaling* effects on the comprehension of text and graphics has been applied within the context of hypermedia, as opposed to multimedia (see Gerjets et al., 2009). The current experiment compared three forms of facilitation of hypermedia learning (prompted referencing, integration scaffolding, and signaling key terms) against a control condition which provided no aids for coordinating text and diagram. The four learning conditions manipulated in this experiment were as follows:

1) A *Control* group learned about the human circulatory system using a hypermedia environment comprising 12 total pages of text and diagrams.

2) An *Integration scaffolding* group used the same hypermedia environment to learn about the circulatory system. At 35 points within the text, integration scaffolding hyperlinks were used to encourage the visual inspection of diagrams at these points and to reduce search time within the diagrams for corresponding elements.

3) A *Key terms* group used the same hypermedia environment to learn about the circulatory system. The same terms which were scaffolded in the integration scaffolding condition were highlighted to direct attention to critical terms within the text.

4) A *Prompted referencing* group used the same hypermedia environment to learn about the circulatory system. At the same points which were scaffolded or highlighted in the previous two conditions, textual prompts were inserted which instructed the learner to reference the diagram. These prompts were intended to encourage the visual inspection of diagrams at these points.

Hypotheses

It was predicted that the integration scaffolding condition would reduce search time for and promote the identification of corresponding elements within text and diagram, as has been demonstrated in previous attention guidance investigations (Ozcelik et al., 2009). According to the theoretical models of text-picture integration, simultaneous activation of textual information and pictorial information is necessary for successful integration to occur, ultimately resulting in a cohesive mental model of both verbal and pictorial information (Mayer, 2005; Schnotz, 2005). As described earlier, my definition of a cohesive mental model is one from which inferences concerning the operating of the physical system can be made. Accordingly, the reduced search time, and therefore simultaneous activation of verbal and pictorial information, from the integration scaffolding condition should lead to better performance on learning outcomes. Additionally, the integration scaffolding condition should reduce extraneous cognitive load, thereby freeing cognitive resources for germane processing. Although the prompted referencing condition provides learners with no support in locating corresponding information within text and diagram, the instruction to reference the diagram at several points within the text was predicted to lead to more frequent inspection of the diagram during learning, when compared to the control and key terms conditions. Finally, the key terms condition will provide the learners with guidance in processing conceptually important terms within the textual representations (Mautone & Mayer, 2001). Based upon these assumptions, the following hypotheses were offered for the experiment:

1) The integration scaffolding condition will lead to the highest learning outcomes and lowest subjective cognitive load ratings.

2) The key terms conditions and the prompted referencing condition will lead to higher learning outcomes and lower subjective cognitive load ratings, when compared to the control condition.

3) The integration scaffolding condition and the prompted referencing condition will both lead to shorter delays between fixations on scaffolded terms and fixations on the corresponding areas within diagrammatic representations. The integration scaffolding condition will have the shortest delays.

4) The integration scaffolding condition will lead to a greater number of fixations, higher total fixation duration, higher proportion of fixations, and higher proportion fixation duration on relevant areas within the diagrams.

5) The integration scaffolding condition will lead to a greater frequency of self-regulated learning monitoring and strategy use during the learning session. No specific hypotheses were made for individual learning strategies or monitoring processes.

Chapter 2

Method

Participants

Eighty (*N* = 80) undergraduate students were recruited using the psychology subject pool available at The University of Memphis. The students in the subject pool were enrolled in introductory psychology courses and received class credit for participating in an experiment of their choice. Participants' mean age was 20 years (range: 18-44; *SD* = 3.53, and their mean GPA was 2.91. Fifty-seven of the participants (71.3%) were female. Only 14 of the participants (17.5%) reported having taken a college-level biology course prior to the experiment and only nine participants (11.3%) reported having work experience in biological fields. The majority of participants in the experiment (47; 58.8%) were college freshmen, 22 (27.5%) were sophomores, six (7.5%) were juniors, and 5 (6.3%) were seniors. Participants demonstrated relatively low knowledge of the human circulatory system, with a mean pretest score on the multiple choice measure of 48% (*SD* = 15%).

Research Design

This study experimentally manipulated the presence of and the type of facilitative interface element intended to enhance learners' use of text and diagram. The experiment is a mixed-factorial design with four levels of the between-subjects factor (experimental condition: control, integration scaffolding, key terms and prompted referencing) and two levels of the within-subjects factor (testing time with pretest and posttest). Participants in all learning conditions viewed up to 12 total pairs of text and diagram[1] within a non-linear self-paced hypermedia learning environment created using Adobe Dreamweaver CS4 (Adobe, 2008) and displayed in Internet Explorer (Microsoft, 2010).

There were multiple dependent product and process measures of learning: 1) pretest and posttest scores on learning measures, 2) several measures of eye-tracking data collected during the learning task; 3) a post-task self-report measure of subjective cognitive load experienced during the task; and 4) measures of self-regulatory behavior coded from think-aloud protocols collected during the learning task (Azevedo, Moos, Johnson, & Chauncey, 2010; Ericsson, 2006; Ericsson & Simon, 1993). The effectiveness of the learning conditions was established through quantitative analysis of two separate learning outcome measures. One measure was primarily aimed at capturing the level of learners' conceptual understanding (i.e., mental models) of the human circulatory system through analysis of the verbalizations regarding the structure, behavior, and function of the human circulatory system (Hmelo-Silver & Pfeffer, 2004) and the flow of blood throughout the body. Manual coding of the qualitative information provided within the first measure allowed quantitative analyses to be conducted. The second measure is primarily directed toward capturing the level of learners' declarative and conceptual knowledge through multiple choice items. Differences in learning outcomes were determined using ANCOVA analyses, with pretest scores as covariates.

[1] Participants can view up to the total 12 pages of text and diagram contained within a hypermedia learning environment, described in more detail within the section *hypermedia learning environment*

Experimental conditions. All participants were randomly assigned to one of the four experimental learning conditions, each employing the same researcher-developed hypermedia learning environment described in detail in the next section.

In the *Control* condition, all participants viewed the hypermedia learning environment without any facilitating features within the texts or diagrams (see Figure 1).

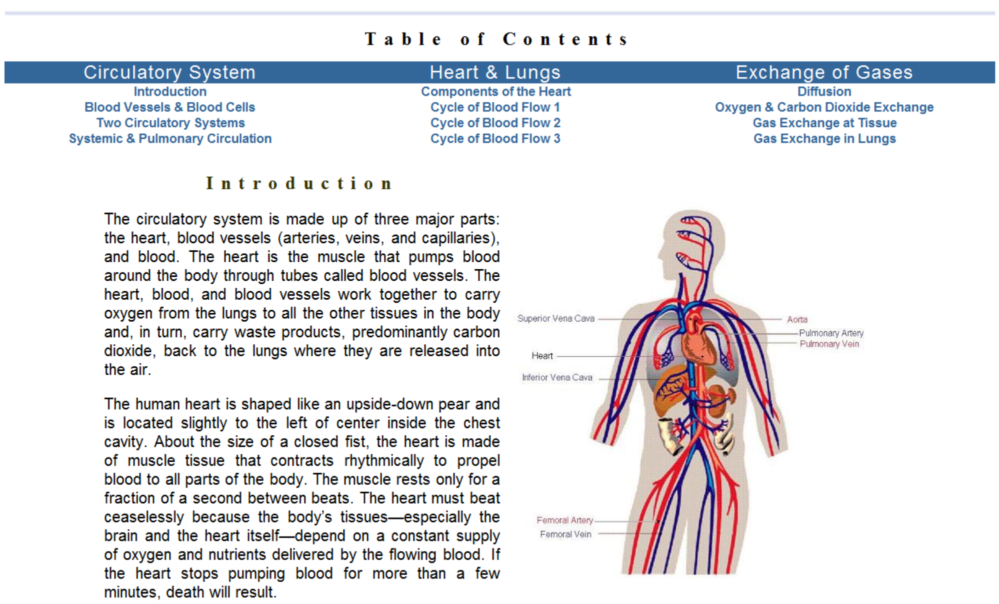

Figure 1. Screenshot of the control condition.

In the *Integration Scaffolding* condition, participants viewed the identical text and diagrams used in the control condition, with the addition of 35 integration scaffolding hyperlinks within the 12 texts. The integration scaffolding hyperlinks consist of important terms (e.g., 'arteries', 'human heart') which are highlighted in blue and underlined within the text. When the mouse hovers over these links, the system highlights the corresponding area(s) of the diagram for as long as the learner's mouse hovers over a term. For example, when a learner hovers over the term 'human heart' while reading about this component, the heart is highlighted within the accompanying diagram (see Figure 2 for this example).

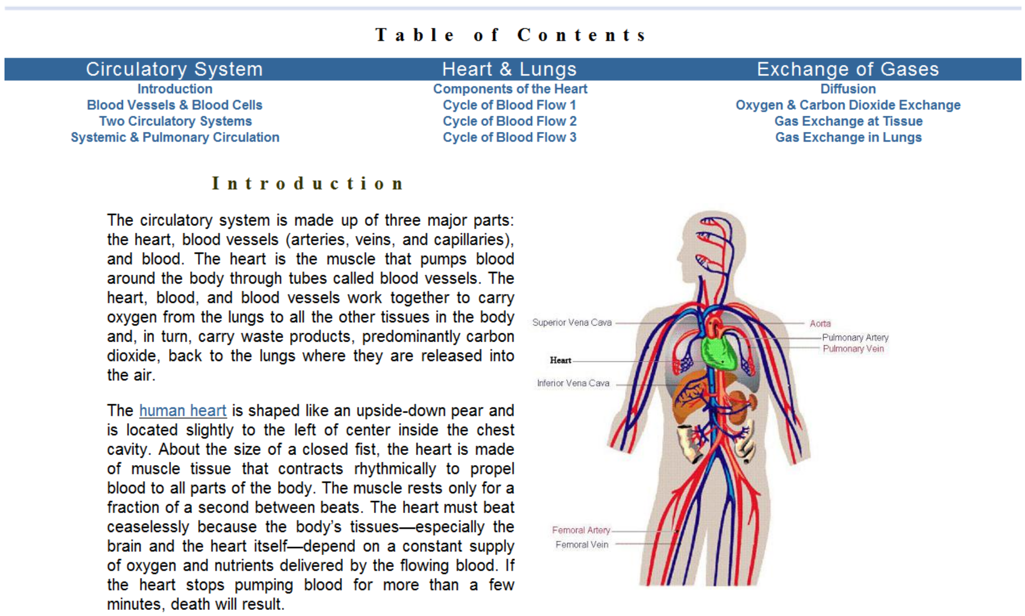

Figure 2. Screenshot of the integration scaffolding condition. Demonstrates the integration scaffold for the human heart.

In the *Key Terms* condition, participants viewed the identical text and diagrams used in the previously described conditions, and the same terms (35 total) that comprise integration scaffolds in the integration scaffolding condition. The 35 terms are highlighted in blue and underlined (see Figure 3). However, when learners hover over the terms in this condition, no component is highlighted within the accompanying diagram. Finally, in the *Prompted Referencing* condition, participants viewed the identical learning environment employed in the control condition, with the addition of prompts to reference the accompanying diagram. Textual prompts to reference the diagram (35 total) appear immediately following the terms which comprise ‘integration scaffolds’ and ‘key terms’ from the two previous conditions (see Figure 4).

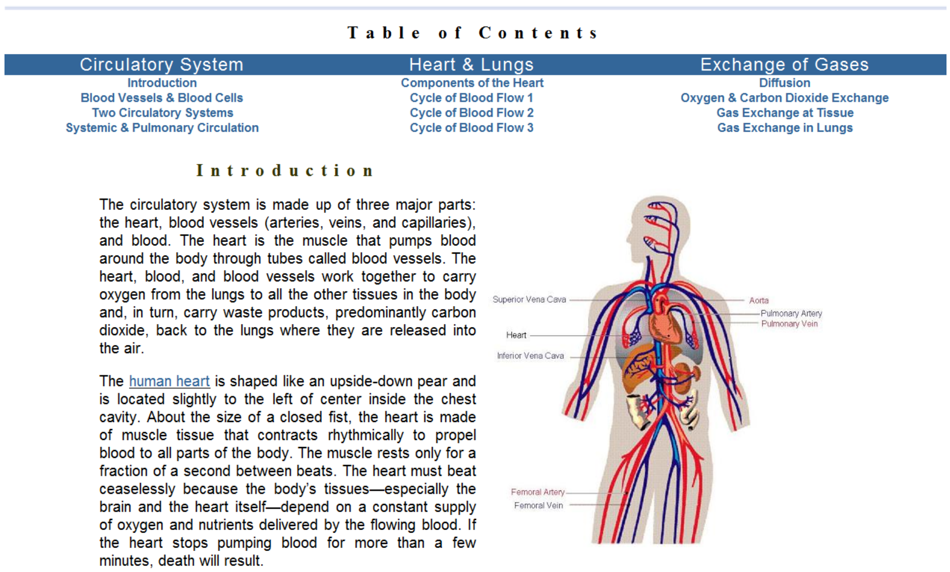

Figure 3. Screenshot of the key terms condition.

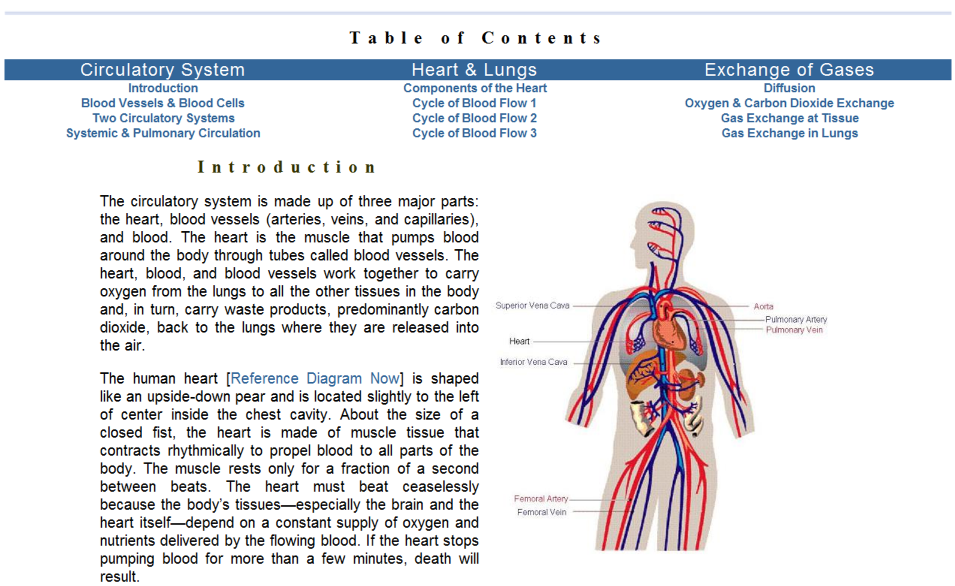

Figure 4. Screenshot of the prompted referencing condition

Apparatus

All participants were seated approximately 64 cm in front of the Tobii T60 eye-tracker (Tobii T60, 2009) throughout the learning task. This system allows researchers to easily determine looking behavior to a high degree of accuracy (0.5 degrees) and high temporal resolution (60 Hz), while compensating for head movements. It is a non-intrusive device because participants do not need to use a bite-bar or detect tracking sensors (the tracking device is built in to the monitor).

Materials

The materials employed in the experiment included paper and pencil materials collected before and after the learning session and the four versions of the researcher-developed hypermedia learning environment used during the learning session.

Paper and pencil materials. The paper and pencil materials included a participant questionnaire, domain knowledge pretest and posttest, and a cognitive load self-report measure (Cierniak et al., 2009; Paas & van Merrienboer, 1994). The participant questionnaire elicited personal demographics and relevant individual differences, including age, gender, level of education, number of biology courses taken, and relevant work experience in health/medicine.

The domain knowledge pretest and posttest were identical (except order of two versions of the multiple choice questions was randomized from pretest to posttest) and included both of the following measures: (a) a diagram interpretation task (see Appendix B) in which think-aloud protocols were collected on the participants' explanation of their understanding of the circulatory system using the three diagrams from the hypermedia learning environment, and (b) a 24-item four-foil multiple choice test (See Appendix C) with both conceptual questions (e.g., What would occur if the mitral valve stopped working?) as well as declarative questions (e.g., What are the three types of blood vessels?).

It was hypothesized that the integration scaffolding condition would positively impact learning gains demonstrated through both learning measures. Because the integration scaffolding method was expected to result in more complete and accurate internal representations (i.e., mental models) of the human circulatory system, each type of knowledge is expected to be promoted through the manipulation. Learners' understanding of the structure, the function of each component, the underlying mechanisms behind those functions, and the flow of blood throughout the body should be demonstrated through their performance on the diagram interpretation task. The multiple choice measure also provided information about learners' declarative knowledge and conceptual understanding of the human circulatory system. No specific hypotheses were offered concerning differential impact of integration scaffolding on different types of internal knowledge representations.

Administration of the diagram interpretation task involved presenting the participant with all three diagrams (in color) used in the learning modules and instructing them:

> On the following page are three diagrams of the circulatory system. Use these three diagrams in any way you would like to describe your understanding of the circulatory system. You can draw on any of the diagrams that you would like to during this task, using the pens provided. **PLEASE TELL ME EVERYTHING YOU CAN ABOUT THE CIRCULATORY SYSTEM.** Be sure to include all the parts and their

purpose, explain how they work both individually and together, and also explain how they contribute to the healthy functioning of the body. If you want to talk about a particular component of the system, you can either write the name of that component on the sheet or just point to it with your pen while referring to it.

Before beginning the diagram interpretation task, participants were given a blue, a red, and a black pen to draw on the provided diagrams in any way they like. The participants were also instructed that they could choose to explain their understanding using any one, two, or all of the diagrams provided (See Appendix B). Each participant's use of the provided diagrams was video recorded from a bird's eye view camera above the sheet of paper (see Figure 5), and the participants' verbalizations were audio recorded for later scoring.

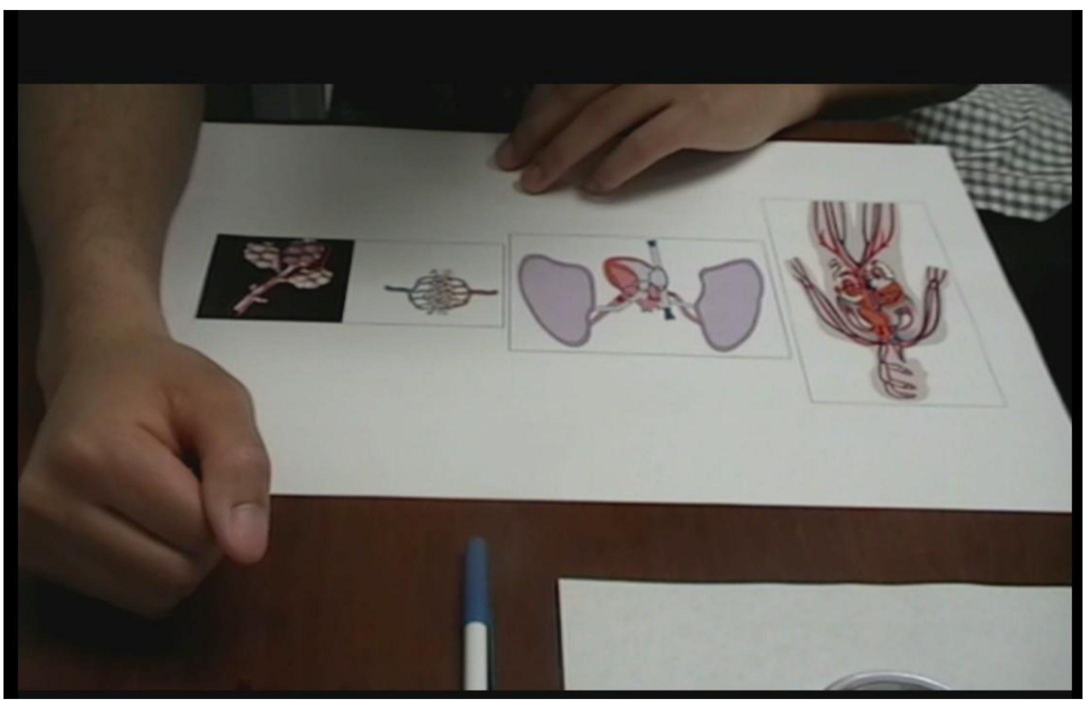

Figure 5. Diagram interpretation task video camera vantage point

The cognitive load self-report measure is a six-point Likert-type scale constructed following previous work on measuring cognitive load experienced by learners (Cierniak et al., 2009; Paas & van Merrienboer, 1994) and includes three questions pertaining to three separate cognitive load constructs (extraneous, intrinsic, and germane cognitive load) from the cognitive load theoretical and empirical work previously published (Sweller, 1988; Sweller & Chandler, 1991; Sweller et al., 1998). A single question was intended to provide a distinct measure for each of the three types of cognitive load: 1) How difficult was it for you to learn with the material? (extraneous cognitive load); 2) How difficult was the learning material for you? (intrinsic cognitive load); and 3) How much did you concentrate during learning? (germane cognitive load). Participants respond to each item by circling the statement that best characterizes their subjective experience during the learning session from 1 (not at all) to 6 (extremely). Appendix D shows the cognitive load self-report measure.

Hypermedia learning environment. The hypermedia learning environment contains a total of 12 pages of researcher-developed text (1,712 words) and diagrams (3 diagrams) about the human circulatory system (Flesch-Kincaid reading level: 10.4). The environment is displayed in a web browser window and was created using Adobe Dreamweaver CS4 (Adobe, 2008). The 12 pages of hypermedia learning content are subdivided into three sections of four pages each: global, intermediate, and local text and diagrams. On each of the four pages within each of the three sections, the diagram related to the topic remains the same, but the text differs from page to page, resulting in 12 unique texts and 3 unique diagrams (see Appendix A). The global level texts and diagram relate to the structure, behavior, and function of the entire circulatory system, including the essential functions of the human circulatory system, the major components of the circulatory system and how blood flows throughout the entire body. The intermediate level texts and diagram relate to the structure, behavior, and function of the heart and lungs within the circulatory system, including the essential functions of the heart and lungs, the major components of these two organs, and how blood flows throughout them. The local level texts and diagram relate to the structure, behavior, and function of the arteries, veins, and capillaries; the essential functions of the capillaries, how oxygen and carbon dioxide are exchanged across the capillary walls, and the flow of blood from heart to capillaries (within the lungs and within the body tissue) and back to the heart are each discussed.

Learners navigated within the learning environment by using hyperlinks located in the top pane of the window, labeled as the table of contents (see Figure 1). The hyperlinks were divided into the three sections, labeled ‘circulatory system’ (global level), ‘heart and lungs’ (intermediate level), and ‘exchange of gases’ (local level). Users were free navigate to any page of the learning environment at any point within the learning session and could allocate study time as they chose to each page of content. Upon selecting and clicking on a hyperlink, the text and diagram associated with that page displayed simultaneously in the two panes below the navigation hyperlinks. Equal learning environment real estate was devoted to textual and diagrammatic representations (although 'white space' is not equivalent due to varying text lengths and diagram sizes). Each participant learned using his or her respective experimental version of the hypermedia learning environment. Among the conditions, the learning environment differed only in the ways described in the research design section.

Procedure

Each participant was run individually through the experiment. On entering the lab, each participant was given as much time as necessary to fill out the informed consent form, followed by as much time as necessary to fill out the participant questionnaire (see Appendix E for flow diagram of experimental procedure). Next, a concurrent think-aloud practice task was used to acclimate all participants to the think-aloud procedure. Each participant was instructed: "Before we turn to the real experiment, we will start with a couple of practice problems. I want you to think aloud while you do these problems," and was administered two multiplication problems to practice the think-aloud procedure[2]. The participant was then read the instructions for and given up to five minutes to complete the diagram interpretation pretest (see Appendix B). Before beginning the diagram interpretation task, the participant was told that it was not necessary to utilize the entire five minutes for the task. The participants were told to alert the experimenter whenever they felt they had stated everything they knew about the human circulatory system. Next, the participant was given up to 10 minutes to complete the multiple choice pretest (see Appendix C). Before beginning the multiple choice test, the experimenter read the instructions aloud for the participant. Each participant's time to complete the diagram interpretation task and time to complete the multiple choice task was recorded by the experimenter.

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[2]Participants need not answer the think-aloud practice problems correctly.

Following the pretest, the experimenter calibrated the eye-tracker to the participant using a standard calibration program provided by the Tobii Studio software suite (Tobii Studio™, 2009). This calibration process involves requesting the participant to visually pursue a red dot around the visual display and fixate upon the center of the dot whenever it stops anywhere within the visual display. The calibration employs nine fixation points in order to attain tight calibration for each participant. Following this calibration task, the software provides the experimenter with a calibration accuracy visual display. According to these results, if the experimenter felt that calibration was not successful, another calibration was conducted. The final calibration accuracy was saved by the experimenter, to ensure accurate calibration for each participant. Participants were instructed that they were free to move their head throughout the learning task, but that their posture should remain stable. In order for accurate eye-tracking results, participants' distance from the monitor needed to remain about 64 cm.

After calibrating the eye-tracker, the experimenter read the learning task instructions to the participant. In addition to general learning task instructions on the learning environment and the task itself, participants were given condition-specific instructions for the four experimental conditions (see Appendix F).The learning task instructions were read aloud by the experimenter and the participant also had access to the typed instructions, located on a copy stand to the left of the computer monitor, throughout the learning task. The participant was told that he or she could take notes during the learning session but that these notes would not be provided to them during the posttest. The participant was then given 20 minutes to learn about the human circulatory system using the hypermedia learning environment. Throughout the learning session, the participant's eye movements were recorded using the Tobii eye-tracker and Tobii Studio software package (Tobii Studio™, 2009; Tobii T60, 2009). Additionally, the participant's verbalizations and behavior were video recorded for later coding and analyses of self-regulated learning behavior. During the learning session, if a participant's posture changed significantly (i.e., leaning in closely to the monitor or slouching back in the chair), the experimenter provided a prompt to return to the initial posture. Also, if learners were quiet for more than a few seconds, the experimenter provided a prompt to continue thinking aloud.

Immediately after the twenty minutes elapsed[3], each participant completed the cognitive load self-report measure. The participant was then given up to 15 minutes (allotted in the same manner as the pretest) to complete the diagram interpretation posttest and multiple choice posttest, without access to any of the notes taken during the learning session or the learning environment. Finally, the participant was debriefed by the experimenter. Appendix G presents the Institutional Review Board approval for the study.

Coding and Scoring

The following section describes the methods used to score and derive the various product measures of learning and process measures of eye-tracking and self-regulated learning from the experiment. The product measures (diagram interpretation task and

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[3]To control for time on task, every participant was given exactly 20 minutes in the hypermedia learning environment. If the learner completed reading all content before the 20 minutes expires, he or she will be instructed to continue until the 20 minutes is elapsed. If the learner did not complete reading all content within the 20 minutes, he or she was not given additional time.

multiple choice test) are presented first, followed by a description of the calculation of eye-tracking measures and the coding of SRL data.

Domain knowledge measures. The diagram interpretation (DI) task was video recorded, transcribed and scored by assigning points for idea units provided by the student with respect to information from four categories of knowledge. Three of these categories are based on the structure, behavior, function framework (see Hmelo-Silver & Pfeffer, 2004). The following four categories were used in scoring the diagram interpretation task:

1) *structure* statements in which learners indicate the location (through pointing or labeling on the sheet) of any component of the system or describe the structure of any component (e.g., “The heart is here [pointing]”; "The heart has four chambers");

2) *function* statements in which learners indicate the function of a given component (e.g., “The heart pumps blood around the body”; "The arteries carry blood away from the heart");

3) *behavior* statements in which learners indicate the underlying mechanism(s) involved in the functioning of a given component (e.g., “The red blood cells pick up the oxygen in the lungs at the air sacs through diffusion”; "The valves stop blood from flowing backward by closing after blood flows through"); and

4) *flow* statements in which learners indicate the flow of blood through the system (e.g., “Blood flows from the right atrium to the right ventricle”; "Blood flows from the pulmonary arteries to the lungs").

For the DI task, each participant was awarded up to two points for each unique[4] correct idea unit generated (e.g., “Veins carry blood toward the heart”) during this task. An idea unit is defined as one piece of explicit information related to one of the four types of information (which concerns the circulatory system[5]). Each statement has the potential to include all correct information, some correct and some incorrect information, or all incorrect information. A previous investigation showed that participants often provide correct and incorrect information within one distinct statement (Witherspoon & Azevedo, 2008). For example, in the previous statement, "Blood flows from the right atrium to the right ventricle," a partially correct verbalization would be "Blood flows from the right atrium to the *left* ventricle." The learner has demonstrated that he/she understands that blood flows from atria to ventricles, but does not know which ventricle the blood flows into from the right atrium. A statement containing relevant information was assigned two points if all information was correct and covered the concept sufficiently, one point if some information was correct, and zero points if none of the information was correct (see Appendix H for scoring rubric and examples). Also, points were awarded for correct diagram additions (e.g., drawing a directional arrow in the correct direction of blood flow or writing correct label for a component) which were not addressed verbally by the participant. These additional points were awarded on the basis of video analysis, when observations were made of correct pen traces of the diagram. Learners' non-verbal diagram additions were scored in exactly the same way as the

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[4] Restatements of the same idea were not counted toward a participant's score on the DI task.

[5] Statements not related to the circulatory system were not coded.

verbalizations. Drawing directional arrows indicating the flow of blood was awarded points toward the *flow* score, whereas labeling components within the diagrams was awarded points toward the *structure* score. An earlier investigation utilizing the same learning measure revealed that these were the only types of information provided by learners through writing on the diagrams provided during the task (Witherspoon & Azevedo, 2008). All points awarded through coding the diagram interpretation tasks was summed within the four categories and each participant received a pretest and posttest score for each of the four categories of information. Additionally, each participant received an incorrect pretest and posttest score for each of the four categories.

Due to errors in recording or transferring video recordings to the computer, four posttest videos were lost and one pretest video was lost. Therefore, 75 participants' diagram interpretation tasks were available for transcription, coding, and analysis. The 75 pretest transcriptions comprised 81 pages (M = 1.08 pages per participant; range: one to three pages) and 10,961 words (M = 146.15 words; range: 4 to 806 words). The 75 posttest transcriptions comprised 93 pages (M = 1.24 pages; range: one to three pages) and 15,410 words (M = 205.47 words; range: 16 to 617 words). The mean time taken to complete the diagram interpretation task at pretest was 1 minute and 53 seconds (range: 31 seconds to 5 minutes). The mean time taken to complete the diagram interpretation task at posttest was two minutes and 38 seconds (range: 42 seconds to 5 minutes).

The multiple choice (MC) pretest and posttest was scored by awarding one point for each correct answer selected by the participant. None of the participants' data for the multiple choice task was lost, so analyses on the multiple choice measure include all 80 participants. The mean time taken to complete the multiple choice test at pretest was 7.4

minutes (range: 4 to 10 minutes). The mean time taken to complete the multiple choice test at posttest was 6.4 minutes (range: 3 to 9 minutes).

Using these coding and scoring procedures for the domain knowledge tests resulted in nine unique scores (DI-structure, DI-function, DI-behavior, DI-flow, DI-incorrect structure, DI-incorrect function, DI-incorrect behavior, DI-incorrect flow, and MC) for pretest and nine unique scores for posttest. Additionally, a total correct DI task score and a total incorrect DI task score was calculated by adding the scores for each of the four categories.

Eye-tracking. An analysis of eye-tracking data is expected to provide insights into the process of effectual and ineffectual coordination between text and diagram. Effectual coordination is characterized as inspecting corresponding information within the text and diagram in a relatively brief manner. According to the theoretical models of text-picture integration, in order for successful integration of textual and pictorial information to occur, the two types of representations must be simultaneously active within working memory. Thus, effectual coordination requires short latency periods between fixations on textual and fixations on corresponding diagrammatic representations. Consequently, ineffectual coordination is defined as the inability to locate the corresponding elements between text and diagram promptly or the failure to locate the corresponding elements at all.

The Tobii Studio software package allows the researcher to define various areas of interest (AOIs) within the visual display for any stimulus presented during experimentation. Within each page of content, several AOIs are defined. First, the text as a whole and the diagram as a whole comprise two distinct AOIs for which the software provides indices of eye-gaze. Next, each textual representation and pictorial representation of the scaffolded terms within the content are defined as individual AOIs. Raw measures of visual attention to the various AOIs are provided by the software package, including fixation count and total fixation durations. These two metrics are used in deriving various measures of effectual and ineffectual coordination described above. Total fixations and total fixation duration on diagrams is computed by totaling across all 12 pages of content. To calculate relevant[6] fixations and fixation duration, the number/duration of fixations on any relevant area in the diagram is totaled across all 12 pages. Proportion scores are derived for relevant fixations and fixation durations by dividing these measures by total fixations/fixation duration on the diagram. A description and illustrative example of each of the measures is provided in Appendix I.

Before obtaining the eye-tracking metrics, the author watched the videos provided by the eye-tracking software. The purpose was to determine that eye-tracking results for the participants were valid. The author viewed the videos, listening to the verbalizations from the participants and observing the eye-tracking accuracy through the fixation points provided through the video analysis. The author determined that much of the eye-tracking data was not valid. Only 8 out of the 20 participants from the integration scaffolding condition and eight out of the 20 participants from the prompted referencing condition had valid eye-tracking data. Thus, in order to include an equal sample size for all four conditions, a random selection process was used to select eight participants from the

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[6] A relevant area of the diagram is defined as any area corresponding to a component which is mentioned (and thus, scaffolded in the experimental conditions) within that page's textual representation.

remaining two conditions. All eye-tracking analyses reported are for the resulting 32 participants (eight from each experimental condition).

Self-regulated learning processes. The think-aloud protocols (Azevedo et al, 2010; Ericsson, 2006; Ericsson & Simon, 1993) collected during the participants' learning session with the computer learning environment were analyzed to determine the participants' use of SRL processes. Azevedo, Cromley, and Seibert (2004) developed a coding scheme for SRL processes which has been fine-tuned to be used in other studies (e.g., Azevedo, Greene, & Moos, 2007; Azevedo, Moos, Greene, Winters, & Cromley, 2008) and this modified coding scheme was used to code participants' verbalizations in the proposed experiment (see Appendix J). This coding scheme is based on several recent theoretical models of SRL (Pintrich, 2000; Winne, 2001; Winne & Hadwin, 1998, 2008; Winne & Perry, 2000; Zimmerman, 2000; 2008).

Pintrich's four-phase process model of SRL informs the coding scheme's five classes of variables: *planning*, *monitoring*, *strategy use*, *handling task difficulty and demands*, and *interest*. Within these five categories, the coding scheme includes 39 SRL processes which previous experiments demonstrate are used by participants in various conditions (Azevedo et al., 2004; Azevedo & Cromley, 2004; Azevedo, Cromley, Moos, Greene, & Winters, in press; Azevedo, Cromley, Winters, Moos, & Greene, 2005; Moos & Azevedo, 2006; Winters & Azevedo, 2005;). *Planning* processes include sub-goal setting, planning, prior knowledge activation, recycling goals in working memory, and time and effort planning. *Monitoring* processes include content evaluation (+ or -), feeling of knowing (+ or -), expectation of adequacy of content (+ or -), evaluation of content as answer to goal, judgment of learning (+ or -), monitoring progress toward goal, monitoring use of strategies, self-question, and time monitoring. Several of the monitoring processes are accompanied by valence which indicates whether the evaluation of content or cognitive states is positive or negative. For example, judgment of learning positive (+) is used to express there *is* an understanding, whereas judgment of learning negative (-) expresses that there is *not* an understanding. *Strategy use* includes coordination of information sources, drawing, using inferences (+ or -), knowledge elaboration, memorizing, using mnemonics, previewing, re-reading, reviewing notes, summarizing (+ or -), and taking notes. In addition to the typical learner use of coordination of informational sources, in which learners engage in purposeful coordinated use of multiple representations (i.e., text and diagram), the coding scheme for this experiment included a *scaffolded* coordination of informational sources, which was coded each time a participant used one of the integration scaffolds provided to the integration condition or referenced the diagram when instructed in the prompted referencing condition. This variable was used partially as a manipulation check on the experimental condition. *Handling task difficulty and demands* processes include task difficulty judgments and help seeking behavior. *Motivation* variables include positive and negative statements of interest and positive and negative statements of affect. The *No Code* variable was coded whenever a statement provided by the participant could not be coded according to the coding scheme because it lacked enough context or was unintelligible.

Student verbalizations during the learning sessions were collected using the think-aloud methodology (Azevedo et al., 2010; Ericsson, 2006; Ericsson & Simon, 1993) and the audio recordings were transcribed by the author for coding. Any statement provided by the participant including more than two *meaningful* words (e.g., *not* ‘um’ or ‘ok’) that were not part of the learning context was segmented according to our coding scheme. Each participant’s transcription was coded using one of the SRL variables for each segment. Following the initial coding, the SRL processes coded for each segment were also collapsed into one of the five categories of processes (*Planning*, *Monitoring*, *Strategy use*, *Handling task difficulty and demands*, and *Interest*) according to the aforementioned category association.

The 32 participants that were used in the eye-tracking analyses were also used for the think-aloud analyses. The transcriptions from these 32 participants resulted in a total of 314 pages (*M* = 9.8 pages per participant; range: six to 16 pages), with a total of 66,741 words (*M* = 2,085.6 words). All participants took exactly 20 minutes to complete the learning session.

Chapter 3

Results

The results from this experiment are reported in two major sections. The product measures (multiple choice test and diagram interpretation task) are reported first, followed by the process measures (eye-tracking, self-regulated learning processes, and cognitive load self-report measure).

Product Measures

Multiple choice measure. In order to determine differences in learners' conceptual and declarative knowledge of the human circulatory system at posttest, an analysis of covariance (ANCOVA) was conducted, using experimental condition as the independent variable, pretest as the covariate, and posttest score as the dependent variable. The results from this analysis indicated a marginally significant effect of experimental condition on posttest scores, when controlling for pretest scores, $F(3, 75) = 2.43$, $p = .072$, $\eta_p^2 = .09$. The assumption of homogeneity of regression slopes underlying the ANCOVA model was met; the interaction between pretest score and experimental condition was not significant, $F(3, 72) = 1.06$, $p = .11$. Estimated marginal means are reported in Table 1, along with descriptive statistics on the pretest and posttest scores.

Table 1

Adjusted Means for Multiple Choice Posttest Scores, by Experimental Condition

	Adjusted Mean	Pretest		Posttest	
	(*SE* = 2.9%)	*M*	*SD*	*M*	*SD*
Control	61.6%	46.3%	11.9%	60.0%	17.5%
Key Terms	60.2%	47.9%	19.5%	59.8%	17.7%
Prompted Referencing	60.4%	51.9%	17.1%	62.9%	17.7%
Integration Scaffolding	69.6%	47.9%	10.9%	69.2%	14.5%

Pairwise comparisons indicated that the integration scaffolding condition significantly outperformed the key terms condition (p = .02) and the prompted referencing condition (p = .03). Additionally, the adjusted posttest score for the integration scaffolding condition was marginally higher than for the control condition (p = .053). None of the remaining comparisons indicated significant differences.

Diagram interpretation task. To determine differences among the experimental conditions in participants' knowledge of the structure, function, behavior, and flow of the human circulatory system, a series of analysis of covariance (ANCOVAs) was run, using experimental condition as the independent variable, each pretest score for the four categories of knowledge (structure, function, behavior, and flow) as well as the total score as the covariate, and the corresponding posttest score as the dependent variable. For each of these tests, the assumption of homogeneity of regression slopes was met.

For the overall score on the diagram interpretation task (the sum of the structure, function, behavior, and flow categories), there was not a significant effect of experimental condition on the posttest score, after accounting for pretest score, $F(3,70)$ = 0.50, p = .69. There was also no significant effect of experimental condition on the posttest score for any of the four categories of knowledge. Adjusted means, standard errors, F values, and significance levels for the test on each category of knowledge are reported in Table 2. Descriptive statistics for the pretest and posttest diagram interpretation task scores are reported in Table 3.

Table 2

Adjusted Means for Diagram Interpretation Task Posttest Scores, by Experimental Condition and Knowledge Category

	Control (*N* = 18)		Key Terms (*N* = 17)		Prompted Referencing (*N* = 20)		Integration Scaffolding (*N* = 20)		
Category	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*F* (sig)
Overall Score	14.44	8.47	17.71	11.68	14.35	8.85	16.70	8.21	0.50 (.69)
Structure	7.75	0.96	10.17	1.01	6.80	0.91	8.43	0.91	2.11 (.11)
Function	3.64	0.60	2.90	0.62	3.59	0.57	3.82	0.57	0.45 (.72)
Behavior	0.54	0.18	0.20	0.18	0.36	0.17	0.34	0.17	0.62 (.61)
Flow	3.57	1.05	3.24	1.07	3.58	1.00	4.21	0.99	0.16 (.92)
Overall Incorrect Score	1.03	0.32	1.20	0.33	1.18	0.30	1.17	0.30	0.55 (.98)

Table 3

Descriptive Statistics for Diagram Interpretation Task, by Experimental Condition and Knowledge Category

	Control (*N* = 18)		Key Terms (*N* = 17)		Prompted Referencing (*N* = 20)		Integration Scaffolding (*N* = 20)		
Category	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*Range*
Overall Pretest Score	4.61	2.70	7.59	11.83	5.75	8.85	5.75	6.16	0 - 49
Pretest Structure	2.44	1.89	5.06	6.92	2.55	4.02	2.85	1.93	0 - 25
Pretest Function	2.11	1.97	1.88	3.53	1.70	2.23	1.95	2.28	0 - 15
Pretest Behavior	0.00	0.00	0.06	0.24	0.20	0.62	0.05	0.22	0 - 2
Pretest Flow	0.06	0.24	0.59	1.97	1.30	3.21	0.90	3.06	0 - 13
Overall Pretest Incorrect Score	0.17	0.51	0.71	1.10	0.45	0.60	0.40	0.94	0 - 4
Overall Posttest Score	14.4	8.47	17.71	11.68	14.35	8.85	16.70	8.21	2 - 53
Posttest Structure	7.22	3.57	11.53	7.10	6.35	4.00	8.20	4.87	0 - 34
Posttest Function	3.78	3.56	2.88	2.62	3.45	2.56	3.85	3.27	0 - 14
Posttest Behavior	0.44	0.98	0.18	0.39	0.50	1.05	0.30	0.73	0 - 4
Posttest Flow	3.00	4.86	3.12	4.54	4.05	5.09	4.35	4.89	0 - 16
Overall Posttest Incorrect Score	0.83	1.15	1.41	1.70	1.20	1.44	1.15	1.60	0 - 6

To further test if the experimental conditions led to differences in participants' knowledge of the human circulatory system, the incorrect statements provided by participants were also analyzed. An analysis of covariance, using experimental condition as independent variable, total incorrect pretest score as covariate, and total incorrect posttest score as dependent variable was conducted. Results indicated that there was not a significant effect of experimental condition on incorrect knowledge of the human circulatory system at posttest, after controlling for pretest score, $F(3, 70) = 0.06$, $p = .98$. Adjusted means, standard errors, *F* values, and significance levels are reported in Table 2

Process Measures

Eye-tracking. As described in the coding and scoring section, several measures of eye-tracking were computed based on the fixation data provided by the eye-tracker. Each of these measures was analyzed using an ANOVA, with the experimental condition as the independent variable. The means and standard deviations of each eye-tracking measure are reported in Table 4.

Table 4

Descriptive Statistics for Eye-tracking Measures for Each Experimental Condition

	Experimental Condition							
	Control		Key Terms		Prompted Referencing		Integration Scaffolding	
Eye-tracking Measures	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Relevant Diagram Fixation Length	9.3	10.8	20.0	15.6	32.1	35.2	47.0	31.7
Total Diagram Fixation Length	93.0	79.6	169.0	73.3	168.5	154.7	202.1	114.9
Relevant Diagram Fixation Count	23.5	23.4	37.4	22.8	42.3	36.9	78.5	50.1
Total Diagram Fixation Count	255.8	215.4	401.8	171.1	341.0	260.9	408.6	210.0

Table 4 (continued)

Descriptive Statistics for Eye-tracking Measures for Each Experimental Condition

	Experimental Condition							
	Control		Key Terms		Prompted Referencing		Integration Scaffolding	
Eye-tracking Measures	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Proportion fixation time on Diagram	0.078	0.066	0.141	0.061	0.140	0.129	0.168	0.096
Relevant Diagram Fixation Length Proportion	0.095	0.030	0.108	0.058	0.195	0.091	0.212	0.066
Relevant Diagram Fixation Count Proportion	0.099	0.036	0.088	0.037	0.136	0.064	0.181	0.071

Results indicated a significant effect of experimental condition on the time spent fixating on relevant portions of the diagrams (relevant diagram fixation length), $F(3, 28) = 3.23$, $p = .04$. Post-hoc comparisons showed that participants in the integration scaffolding condition had significantly longer total fixation times on relevant portions of the diagrams than the control group ($p = .006$), and the key terms group ($p = .04$). None of the remaining comparisons were significant for the relevant diagram fixation length measure. There was no significant difference among the groups on the total time spent fixating on the diagrams (total diagram fixation length), $F (3, 28) = 1.40$, $p = .26$.

Eye-tracking results further indicated that experimental condition had a significant effect on the total fixations on relevant parts of the diagrams (relevant diagram fixation count), $F(3, 28) = 3.56$, $p = .03$. Post-hoc comparisons showed that participants in the integration scaffolding condition had significantly more fixations on relevant parts of the diagram than the control group ($p = .004$), the key terms group ($p = .03$), and the prompted referencing group ($p = .048$). None of the remaining comparisons were significant for the relevant diagram fixation count measure. There was no significant difference in total the number of fixations on the diagram (total diagram fixation count), $F(3, 28) = 0.86$, $p = .48$.

In addition to the raw measures of eye-tracking, proportional measures were computed, to determine if the experimental conditions had an impact on the distribution of looking behavior within the diagrams. If a given experimental condition has a positive impact on ability to locate relevant information, then the proportion of time or proportion of fixations on relevant (vs. irrelevant) areas of the diagrams should be higher for this condition. Indeed, experimental condition had a significant effect on the proportion of time participants spent looking at relevant areas of the diagram (relevant diagram length proportion), $F(3, 28) = 6.66$, $p = .002$. Post-hoc comparisons indicated that participants in the integration scaffolding condition spent a greater proportion of their time inspecting diagrams on relevant areas, compared to the control group ($p = .001$) and compared to the key terms ($p = .004$). Additionally, the prompted referencing group spent a greater proportion of their time on relevant areas, compared to the control group ($p = .005$) and compared to the key terms group ($p = .01$). Both the integration scaffolding condition and the prompted referencing condition spent about 20% of the time that they were fixating on the diagram looking at relevant portions of the diagram, about twice the proportion for the other two conditions. None of the remaining comparisons were significant for the relevant diagram length proportion measure. Results also indicated that experimental condition had a significant effect on the proportion of relevant fixations on diagrams (relevant diagram count proportion), $F(3, 28) = 4.72$, $p = .009$. Post-hoc comparisons indicated that the participants in the integration scaffolding condition had a greater proportion of fixations on relevant areas, compared to the control group (p = .006) and compared to the key terms condition (p = .002). None of the remaining comparisons were significant for the relevant diagram count proportion measure.

An identical set of analyses, using the entire sample of participants was conducted to ascertain that the results obtained with the subset of accurate eye-tracking data points were not due to a selection bias. The pattern of results using this inclusive data set were identical to the pattern found using the subset. One exception was that participants in the prompted referencing condition had a significantly greater proportion of fixations on the relevant areas, compared to the control group (p = .02). The results from these additional analyses confirm that the results obtained with only the accurate eye-tracking participants were not due to a selection bias for those participants who followed posture instructions.

Self-regulated learning processes. A one-sample t-test was conducted, using only the integration scaffolding condition, to determine that the experimental manipulation had its intended effect, leading participants to utilize the integration scaffolds provided. The one-sample t-test was used to ascertain that the frequency of observation for the SCOIS variable (scaffolded coordination of information sources) was significantly greater than zero. This analysis indicated that these participants did indeed utilize the integration scaffolds provided, t (7) = 4.735, p = .002. The initial frequency analysis of the SCOIS variable indicated that the integration scaffolding condition used the integration scaffolds more often than the prompted referencing condition, followed instructions to reference the diagram (M_{IS} = 14.75; M_{PR} = 5.00). An independent samples t-test was conducted to determine if this difference was statistically significant. The results of this analysis indicated that the integration scaffolding condition did utilize the integration scaffolds more often than the prompted referencing condition followed the prompts to reference the diagram, t (14) = 2.35, p = .03, Cohen's d = 1.17.

An initial frequency analysis of the SRL processes indicated that there were no observations of six of the SRL processes (negative evaluation of adequacy of content [EAC-], evaluate content as answer to goal [ECAG], drawing [DRAW], help seeking behavior [HSB], positive affect [AFF+], and negative affect [AFF-]). Due to lack of observations for these variables, they are not displayed in the frequency table and were not analyzed for differences among groups. The remaining 32 SRL processes (see Appendix J) were analyzed using analysis of variance (ANOVA) to determine if the experimental conditions had a significant effect on learners' use of self-regulatory processes.

Due to the number of tests run on the SRL processes, the bonferroni correction procedure was applied, resulting in significance level of α = .0016 (.05/32). A significant effect of experimental condition was found for only one SRL process, correct summarization, F (3, 28) = 6.83, p = .001. Table 5 presents raw frequencies and mean deployment of each individual process and each class of SRL processes. Post-hoc comparisons indicated that participants in the integration scaffolding condition verbalized significantly more correct summarizations than the control condition (p < .001), than the key terms condition (p = .02), and than the prompted referencing condition (p = .002). None of the remaining comparisons were statistically significant. Although the ANOVA for correct summarization indicated that the integration scaffolding condition deployed this process more often, the distribution of SRL processes across participants is often non-normal. Thus, a non-parametric test, such as the chi-square test, may be more

Table 5

Descriptive Statistics for SRL Classes and Processes, by Experimental Condition

SRL Class and Process	Control (*N* = 8) Raw Frequency	Control (*N* = 8) *M*	Key Terms (*N* = 8) Raw Frequency	Key Terms (*N* = 8) *M*	Prompted Referencing (*N* = 8) Raw Frequency	Prompted Referencing (*N* = 8) *M*	Integration Scaffolding (*N* = 8) Raw Frequency	Integration Scaffolding (*N* = 8) *M*
Planning	**7.00**	**.88**	**20.00**	**2.50**	**30.00**	**3.75**	**18.00**	**2.25**
Prior Knowledge Activation	7.00	.88	17.00	2.13	24.00	3.00	10.00	1.25
Planning	.00	.00	.00	.00	.00	.00	1.00	.13
Recycle Goal in Working Memory	.00	.00	.00	.00	1.00	.13	.00	.00
Sub-Goal	.00	.00	2.00	.25	.00	.00	7.00	.88
Time and Effort Planning	.00	.00	1.00	.13	5.00	.63	.00	.00
Monitoring	**38.00**	**4.75**	**40.00**	**5.00**	**90.00**	**11.25**	**25.00**	**3.13**
Content Evaluation (-)	3.00	.38	5.00	.63	15.00	1.88	1.00	.13
Content Evaluation (+)	.00	.00	2.00	.25	1.00	.13	1.00	.13
Evaluate Adequacy of Content (+)	1.00	.13	3.00	.38	3.00	.38	.00	.00
Feeling of Knowing (-)	5.00	.63	.00	.00	6.00	.75	5.00	.63
Feeling of Knowing (+)	11.00	1.38	7.00	.88	19.00	2.38	6.00	.75
Judgment of Learning (-)	2.00	.25	8.00	1.00	10.00	1.25	6.00	.75
Judgment of Learning (+)	5.00	.63	6.00	.75	16.00	2.00	4.00	.50
Monitoring Progress Toward Goal	.00	.00	1.00	.13	.00	.00	.00	.00
Monitoring Use of Strategies	1.00	.13	1.00	.13	9.00	1.13	.00	.00
Self-Question	5.00	.63	5.00	.63	4.00	.50	2.00	.25
Time Monitoring	5.00	.63	2.00	.25	7.00	.88	.00	.00
Learning Strategies	**255.00**	**31.88**	**405.00**	**50.63**	**374.00**	**46.75**	**397.00**	**49.63**
Coordination of Information Sources	32.00	4.00	113.00	14.13	70.00	8.75	35.00	4.38
Incorrect Inference	1.00	.13	1.00	.13	.00	.00	3.00	.38
Correct Inference	6.00	.75	8.00	1.00	5.00	.63	7.00	.88

Table 5 (continued)

Descriptive Statistics for SRL Classes and Processes, by Experimental Condition

SRL Class and Variable	Control (*N* = 8) Raw Frequency	Control (*N* = 8) *M*	Key Terms (*N* = 8) Raw Frequency	Key Terms (*N* = 8) *M*	Prompted Referencing (*N* = 8) Raw Frequency	Prompted Referencing (*N* = 8) *M*	Integration Scaffolding (*N* = 8) Raw Frequency	Integration Scaffolding (*N* = 8) *M*
Knowledge Elaboration	1.00	.13	13.00	1.63	4.00	.50	6.00	.75
Memorization	16.00	2.00	19.00	2.38	3.00	.38	3.00	.38
Mnemonic	.00	.00	1.00	.13	.00	.00	.00	.00
Preview	60.00	7.50	63.00	7.88	70.00	8.75	34.00	4.25
Read Notes	3.00	.38	1.00	.13	2.00	.25	2.00	.25
Re-read	74.00	9.25	59.00	7.38	57.00	7.13	22.00	2.75
Scaffolded Coordination of Information Sources	.00	.00	.00	.00	40.00	5.00	118.00	14.75
Incorrect Summarization	4.00	.50	3.00	.38	6.00	.75	4.00	.50
Correct Summarization	21.00	2.63	59.00	7.38	39.00	4.88	118.00	14.75
Take Notes	37.00	4.63	65.00	8.13	78.00	9.75	45.00	5.63
Handling Task Difficulty and Demands	**3.00**	**.38**	**.00**	**.00**	**1.00**	**.13**	**.00**	**.00**
Task Difficulty Statement	3.00	.38	.00	.00	1.00	.13	.00	.00
Motivation	**1.00**	**.13**	**5.00**	**.63**	**10.00**	**1.25**	**3.00**	**.38**
Negative Interest Statement	1.00	.13	2.00	.25	1.00	.13	.00	.00
Positive Interest Statement	.00	.00	3.00	.38	9.00	1.13	3.00	.38
No Code	**48.00**	**6.00**	**40.00**	**5.00**	**76.00**	**9.50**	**29.00**	**3.63**

appropriate in this scenario (see Azevedo et al., 2008). As such, the median deployment of correct summarization was determined and each participant was dummy coded as at/above or below the median (median = 6). The results of the chi-square test indicated that the distribution of participants above or below the median differed, given the experimental condition, χ^2 (3, N = 32) = 10.42, p = .02, ϕ = .57. A greater number of integration scaffolding condition participants (n = 8) were above the median, compared to the control condition (n = 2). Table 6 presents the cross-tabulation of frequencies for experimental condition by the two levels (at/above vs. below median) of the positive summarization variable.

Table 6

Number of Participants At/Above or Below the Median, by Experimental Condition

	Experimental Condition			
	Control (N = 8)	Key Terms (N = 8)	Prompted Referencing (N = 8)	Integration Scaffolding (N = 8)
Below median	6	4	5	0
At/Above median	2	4	3	8

In addition to the analyses on the individual SRL processes, analyses were conducted on the classes of SRL processes. For these analyses, a series of ANOVAs were conducted, using experimental condition as the independent variable, and frequency of deployment of each class of SRL (*planning, monitoring, learning strategies, handling task difficulty and demands*, and *motivation*) as the dependent variable. A marginally significant effect of experimental condition was found for one class of SRL processes, namely learning strategies, F (3, 28) = 2.80, p = .058. Post-hoc analyses indicated that the integration scaffolding condition deployed significantly more learning strategies than the control condition ($p = .02$). Additionally, the key terms condition deployed significantly more learning strategies than the control condition ($p = .02$).

Cognitive load measure. A series of analysis of variance (ANOVAs) were conducted on the self-reported cognitive load from the cognitive load measure to determine if the experimental condition had a significant effect on learners' perception of the cognitive load imposed by the learning materials (Cierniak et al., 2009; Paas & van Merrienboer, 1994). Each type of cognitive load (extraneous, intrinsic, and germane) and the total reported cognitive load was used as a dependent variable in an ANOVA with the experimental condition as the independent variable. Results indicated no significant effect of experimental condition on total cognitive load, $F(3, 76) = 0.21$, $p = .89$. Additionally, there was no significant effect of experimental condition on intrinsic, $F(3, 76) = 0.32$, $p = .81$, extraneous, $F(3, 76) = 0.39$, $p = .76$, or germane cognitive load, $F(3, 76) = 0.30$, $p = .82$. Table 7 presents descriptive statistics on the cognitive load measure.

Table 7

Descriptive Statistics for Cognitive Load Measure, by Experimental Condition

	Experimental Condition							
	Control		Key Terms		Prompted Referencing		Integration Scaffolding	
Type of Cognitive Load	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Intrinsic	2.35	1.04	2.55	1.32	2.30	1.30	2.60	0.99
Extraneous	2.15	1.23	1.95	0.76	2.30	1.08	2.20	1.11
Germane	4.35	1.04	4.35	0.88	4.10	1.25	4.40	1.19
Total	8.85	1.79	8.85	1.81	8.70	2.75	9.20	1.77

Chapter 4

Discussion

This goal of this experiment was to answer two primary questions. First, what form of support is optimal to assist learners in integrating information from a textual representation with information from a diagrammatic representation? Second, why does this form of support promote learning? The experiment also had one secondary question: Do the forms of support previously shown to be beneficial to those learning with multimedia learning environments also aid learners who use hypermedia learning environments? The following discussion interprets the results of the reported experiment, with an emphasis on what implications can be drawn from the results toward theory, education, and methodological issues.

What form of support is optimal to assist learners in integrating information from a textual representation with information from a diagrammatic representation?

The results from the learning outcome measures indicated that the integration scaffolding condition assisted learners in gaining conceptual and declarative knowledge about the human circulatory system. The integration scaffolding condition significantly outperformed all three remaining conditions on the multiple choice posttest measure of circulatory system knowledge. This suggests that the scaffolds directed attention to corresponding elements of the diagram in a just-in-time fashion and that process facilitated the construction of coherent internal mental representations of the instructional content. The remaining three conditions did not differ from one another in adjusted posttest scores. This indicates that learning is not promoted through signaling important key terms or through prompting learners to reference the diagram at the same points as were scaffolded by the integration scaffolds.

Previous empirical work has shown that signaling text elements can be beneficial to learners in selecting relevant information from a textual representation and lead to better recall of these relevant elements (Mautone & Mayer, 2001). It should be noted that the signals used in Mautone and Mayer's (2001) study did not signal the structural components depicted in the animations, but rather signaled the words which conveyed spatial comparisons, such as 'longer' or 'shaped differently'. It may be that simply signaling key terms (the structural components which are depicted in the accompanying diagram) does not assist learners in understanding the organizational structure of the text, and therefore, does not benefit learning outcomes. Descriptively, the key terms condition coordinated text and diagram more (See Table 4) than any experimental conditions. However, I will discuss later an explanation as to why this high amount of visual switching between text and diagram was not beneficial to these learners.

Results from the experiment indicated that those in the prompted referencing condition did not learn more about the human circulatory system than those in the control condition. An explanation may be provided through inspection of the amount of adherence to the visual prompts in this condition. On average, participants in the prompted referencing condition visually inspected the diagram, when prompted, only five times throughout the learning session. Considering that there are 35 prompts in the learning materials, this means that the prompted referencing condition participants, on average, followed the prompts 14% of the time (5/35). If instructions to adhere to the prompts were more firm, these participants may have inspected the diagram more often and benefited from this condition. On the other hand, it may be that the addition of irrelevant text (i.e. inserting 'Reference Diagram Now') in the textual representation detracts attention from relevant text, if only momentarily. The addition of instructions within the learning content may increase extraneous cognitive load and reduce available cognitive resources for the learning task.

The results from the diagram interpretation task were disappointing. The non-significant findings provide no information as to how the different manipulations might influence learners' knowledge of the structure, function, behavior, and flow of the circulatory system. This unfortunate finding may be due to instructions which are not completely clear in conveying the purpose of the diagram interpretation task (see instructions on page 29). Although the participants were instructed to explain everything they knew about the human circulatory system, including the parts, how they work together, and how they contribute to the healthy functioning of the body, the learners may still have been unclear as to what kind of information was most important to provide. Most participants seemed to focus on providing names for the various components within the diagrams, spending little time describing the function or behavior of those components and little time on describing the flow of blood through the system. More explicit instructions as to what kinds of information are being tested in the task might assist researchers in obtaining more informative results. Additionally, the low prior knowledge of the participants, as evidenced through a mean pretest score of 48% on the multiple choice measure, might account for the inability of these students to verbalize more sophisticated knowledge at posttest. However, participants' knowledge of the structure, function, behavior, and flow of the circulatory system did increase from pretest to posttest. Their posttest scores were, on average, nearly three times as high as at pretest (see Table 3).

Educational implications. So far, we have determined that the integration scaffolding technique leads to better learning outcomes compared to a control condition, compared to a signaled condition, and compared to a condition which prompts learners to reference the diagram at these same points. Educationally, these results imply that students learn better from hypermedia learning environments which include attention guidance mechanisms such as the one employed in this study (i.e., integration scaffolding). Previous work on the split-attention problem has used integrative displays, in which textual information is integrated into the diagrammatic representation, to reduce the physical space between a textual representation of a concept and its corresponding diagrammatic representation (Chandler & Sweller, 1991; Moreno & Mayer, 1999). The assumption underlying the integrative approach is that through making verbal and pictorial information spatially contiguous, one can reduce the need to retain verbal information (from the textual representation) in mind while visually searching the diagrammatic representation for the corresponding pictorial representation (Cierniak et al., 2009; Tarmizi & Sweller, 1988). However, this form of integration may not be feasible with long expository texts in the absence of animations. If one does choose to use integrative animations, the creation of such animations for multiple domains such as biology, engineering, and mathematics is costly and requires that the creators understand instructional design principles. Additionally, wide-spread dissemination of these animations assumes that the schools have capacity to view the created animations on their hardware. A simpler way to reduce the latency between reading about a component and viewing the corresponding pictorial representation is through the integration scaffolds used in this experiment. This method has shown to be effective in increasing learning outcomes. The next major question is why?

Why does integration scaffolding promote learning?

To answer the question of why the integration scaffolding technique led to better learning outcomes, we turn to the process data collected in the experiment. The eye-tracking measures, the SRL process analyses, and the cognitive load measure were used in the experiment to allow us to determine why benefits to learning occurred. The answer to this question should be theoretical relevant to Mayer's model (2005), Schnotz's model (2005), and the Cognitive Load Theory (Sweller et al., 1998). Each process measure will be discussed individually and the implications of all three will be discussed at the end of this section.

Eye-tracking. The results from the eye-tracking measures indicated that the participants in the integration scaffolding condition inspected relevant areas of the diagram more often and for a longer total period of time (summed across fixations) than the control group and the key terms group. Additionally, the participants in the integration scaffolding condition inspected relevant areas of the diagram more often than the prompted referencing condition. It should be noted that there was no significant effect of experimental condition on the total fixations on or total fixation time on the diagram as a whole. This means that no experimental condition spent more or less time inspecting the diagrams, but the differences were only in *where* within the diagrams the participants were looking. The integration scaffolding condition spent more time and more fixations on the relevant areas, as would be expected through the integration support provided, in highlighting corresponding pictorial representations to the current verbal representation.

This finding suggests that the reason that the learners in the integration scaffolding condition had higher learning outcomes was because they were better able to locate corresponding information within the diagram, given the current verbal information they were reading.

In order to determine whether the learners in the integration scaffolding condition were better able to locate the relevant information, proportional eye-tracking measures were calculated. The proportional relevant fixation length variable represents the amount of time spent looking at relevant areas, divided by the total diagram fixation time. The resulting proportion gives us the proportion of the time spent inspecting diagrams which was devoted to inspecting relevant areas. According to the results, the integration scaffolding condition spent a significantly larger proportion of the time ooking at relevant areas to that particular page of content. The the integration scaffolding condition spent a significantly lower proportion of the time they were inspecting diagrams looking at *irrelevant* areas to that particular page of content. The implication is that the integration scaffolding manipulation led to reduced search time for corresponding elements in the diagrams. However, search time was not actually measured in the current report, a point discussed in the future directions section.

Taking the eye-tracking findings together, they suggest that the underlying reason behind the observed learning benefits for the integration scaffolding condition, at least in part, is due to the scaffolds' ability to guide learners' attention to relevant areas of the diagrammatic representations and reduce search time for the corresponding elements. The assistance provided by the integration scaffolds likely reduces extraneous cognitive load imposed by the learning materials, especially when the diagrams are as complex as the intermediate level diagram depicting the heart and lungs. This reduction in extraneous cognitive load frees up resources for germane processing for schema construction and automation. The germane processing component will be discussed in the next section on the conclusions from the SRL processes analysis.

Self-regulated learning processes. The results from the SRL process analyses indicated that the integration scaffolding condition verbalized more correct summarizations of the learning content, compared to all remaining conditions. This finding can be related to the germane processing component of the Cognitive Load Theory (Sweller et al., 1998). The earlier analysis of the eye-tracking data led us to assume that extraneous cognitive load was reduced through the integration scaffolding condition. These free resources seem to have been allocated toward germane processing in the form of constructing summaries of the learning content. Not only did the learners engage in summarization, but the summaries were correct more often than incorrect. The distribution of incorrect summaries across the experimental conditions was equivalent. However, the integration scaffolding condition generated over twice as many correct summarizations than the next closest learning condition, key terms. The integration scaffolding condition verbalized nearly six times as many correct summarizations as the control condition. Unfortunately, the only SRL process which was more frequent in the integration scaffolding condition was correct summarization. One would also expect that these germane processes would relate to more sophisticated learning strategies such as making inferences and elaborating with prior knowledge. However, the small sample size for this analysis (N = 32) may not provide enough statistical power to obtain significant results. Additionally, the low prior knowledge demonstrated by low pretest multiple choice scores suggests that the learners in the experiment may not have had sufficient prerequisite knowledge to engage in these more sophisticated learning strategies.

The results from the analysis of SRL processes suggest that the integration scaffolds reduce search time and therefore reduce extraneous load; this reduced extraneous load frees resources for germane processes such as summarization. Unfortunately, the results from the cognitive load measure do not support the assumption that cognitive load is affected by the experimental conditions and the methodology used to measure cognitive load does not afford the opportunity to capture fluctuations in load across the learning session.

Cognitive load measure. The results from the cognitive load measure were quite disappointing. There were no significant differences among the groups on any of the types of cognitive load (extraneous, intrinsic, or germane), nor on total reported cognitive load. The measure itself may not be discriminating enough among these three types of cognitive load. The questions related to intrinsic and extraneous cognitive load (intrinsic: How difficult was the learning material for you?; extraneous: How difficult was it for you to learn with the material?) are very similar and may not allow participants to distinguish that they are actually asking two different things. In fact, the correlation between these two items was quite high, $r = .62$, $p < .001$. Additionally, the germane cognitive load question (How much did you concentrate during learning?) did not significantly correlate with multiple choice posttest scores, $r = .08$, $p = .51$, as would be expected (Cierniak et al., 2009). The original construction of these items was in German and they were translated to English for a scientific publication. Perhaps something was lost in translation? Limitations to the use of the self-report cognitive load measure are discussed further in the limitation section.

Theoretical implications. The results from the eye-tracking and SRL measures provide support to Mayer's model (2005) and Schnotz's model (2005) of text-picture integration. Under both of these models, one assumption is that successful integration requires that verbal information and pictorial information be simultaneously active in working memory. The eye-tracking results suggest that the integration scaffolding condition had shorter search times for corresponding elements in the diagram. This can be extended to conclude that the scaffolds reduce search time, thereby allowing the corresponding verbal and pictorial information to be simultaneously active. Ultimately, this results in a facilitation of the construction of internal mental representations and better learning outcomes. The SRL results suggest that the integration scaffolding condition engaged in more appropriate organization of information, leading to the better capacity to correctly summarize the learning content.

The results of the experiment provide somewhat supportive evidence of the Cognitive Load Theory (Sweller et al., 1998). Although there were no differences in reported cognitive load among the experimental conditions, the integration scaffolding condition was constructed in hopes of reducing extraneous load and the eye-tracking results suggest that extraneous load was, indeed, lowered by this condition. An explanation for the high frequency of observation of coordinating informational sources in the key terms condition can be attributed to cognitive load theory. Although this condition may have led to greater (although not statistically significant) visual switching between text and diagram, because the search for corresponding elements in the diagram was not supported through any attention guidance feature (as in the integration scaffolds), these learners likely spent a significant amount of time trying to locate relevant information in the diagrams, and may have, in fact, given up trying to locate the corresponding components. This search time likely imposed a greater extraneous cognitive load, leading to the inability of this condition to promote better learning outcomes. These learners may have wasted precious moments in the learning session struggling to find the corresponding components in the diagram, thereby reducing time and cognitive resources available for germane processing.

Methodological implications. The experiment demonstrated that the cognitive load self-report measure employed was not successful at differentiating among successful learners and unsuccessful learners (per the lack of correlation between germane load self-report and posttest scores). This suggests that this measure may not be appropriate for discriminating among the three types of cognitive load. More deliberate construction of self-report cognitive load measures should be undertaken, and multiple items representing the three constructs should be devised. Until such time, more objective measures, such as dual-task (Paas, Tuovinen, Tabbers, van Gerven, 2003), might be more appropriate for capturing total cognitive load imposed but the learning environment. Additionally, the dual-task methodology would be more effective in capturing fluctuations of cognitive load throughout the learning task.

The experiment did support the use of eye-tracking methodology to uncover underlying reasons behind observed multimedia or hypermedia effects. The results provided sound grounds for making conclusions about the mechanism behind the integration scaffolding effect evidenced in the experiment. Other multimedia and hypermedia experiments should also employ eye-tracking methodology to determine *why* observed effects occur. One drawback to the use of the particular eye-tracker employed in this experiment is that, unless the participants keep their posture stable, much of the data will be invalid.

The experiment supports the use of think-aloud protocols to capture learners' online cognitive processing with multimedia and hypermedia environments (see Azevedo et al., 2010 for a review). Although only one SRL process was found to differ among the groups, this finding was critical in making the argument that the integration scaffolding condition frees resources for germane processing.

The disappointing results from the diagram interpretation task may indicate the need to construct more directive instructions for the participants. Although this measure was successfully applied in an earlier investigation (Witherspoon & Azevedo, 2008), considering that the multiple choice measure was able to capture differences among the conditions, the diagram interpretation task failed to discriminate among differing amounts of knowledge in the four categories represented. In future studies employing this measure, care should be taken to develop adequate instructions and pilot testing of the measure should be conducted.

Limitations

Several limitations to the experiment have already been introduced. For example, the cognitive load measure employed seems inadequate in discriminating among successful and unsuccessful learners. A better cognitive load measure may be objective measures such as dual-task methodology. A major limitation to the experiment was the inability to demonstrate differences among the conditions in reported cognitive load. According to cognitive load theory, as expertise in a domain increases, intrinsic cognitive load will decrease due to learners' ability to chunk information into meaningful units and activate and make use of these chunks in a more efficient manner (Sweller et al., 1998). Unfortunately, because the cognitive load measure was administered at the end of the learning session, fluctuations in learners' cognitive load (self-reported or otherwise) could not be captured. Evidence for such fluctuations may be captured through the use of dual-task methodology, rather than self-report measures. A major limitation to self-report measures in general is the susceptibility of such measures to response bias. More specifically, cognitive load self-report measures may be subject to bias due to unreliable responses provided by the participant (Brunken, Plass, & Leutner, 2003). Learners are notoriously inaccurate when reporting metacognitive processes, often overestimating understanding of instructional content (Hacker, Dunlosky, & Graesser, 2009; Nelson & Dunlosky, 1991; Theide & Dunlosky, 1994). As previously discussed, the diagram interpretation task also did not prove sensitive in determining differences in the knowledge of the structure, function, behavior, or flow of the human circulatory system. More explicit instructions may alleviate this problem in the future.

Another limitation of the investigation is that the analysis on the SRL processes was undertaken only on a subset of the data available. Results may differ if all videos are transcribed and coded, possibly leading to the ability to identify more SRL processes which were promoted by the integration scaffolding. Additionally, inter-rater reliability could not be obtained because the coding of SRL processes was performed only by the author.

Although the theoretical basis and conclusions drawn from the experiment relate to the accuracy and completeness of learners' mental models, a unique mental model measure was not employed. The diagram interpretation task was used following the assumption that when learners' mental models of the circulatory system are more complete and accurate, they will be better equipped to produce correct statements on the structure, function, behavior, and flow of the system. However, this measure was not sensitive to differences in knowledge more broadly, so differences in learner mental models were not detected using the diagram interpretation task.

Generalizability. Due to the scope of the project, the population employed in this experiment was drawn entirely from the undergraduate population at The University of Memphis. As with most experimental research programs, generalizability to the greater population can be called into question. The selection of exclusively college enrollees, the low prior knowledge of the participants, and the large percentage of female participants (71%) limits any attempt to make general claims for other populations. The campus is in an urban setting in the Southeastern United States, so findings also might not generalize to rural or suburban settings or to other regions of the United States.

The learning session that the learners engaged in was relatively short compared with more realistic study sessions that students would undertake in classroom settings. It is yet to be determined whether the positive impact of integration scaffolds would extend to situations where students are using the learning materials for hours at a time. However, one strength of the design of this experiment is that it utilized hypermedia rather than the multimedia learning materials investigated by other researchers. Hypermedia is a more ecologically valid learning context, where students on their own are free to navigate to any instructional content piece at any time.

Future Directions

More work is necessary to capitalize on the potential of the existing data from the experiment. First, the eye-tracking data provided by the eye-tracker software (Tobii Studio™, 2009) affords the researcher the opportunity to undertake more sophisticated fixation trajectory analyses. For example, one measure yet to be obtained is the search time measure. This measure would represent the amount of time elapsed from fixation on a textual representation (e.g., 'mitral valve') to fixation on its corresponding pictorial representation (i.e., the depiction of the mitral valve in the diagram). This measure should directly isolate that time which elapses while fixating anywhere within the diagram, thus eliminating the chance that the search time would be inflated by additional reading time within the text. Another measure might capture the coupling between the fixations on textual representations and the corresponding pictorial representations in the diagram. How often do fixations on the text about component A result in fixations on the depiction of component A? Do learners also inspect surrounding components (Hegarty & Just, 1993)?

Next, more analyses can be conducted on the think-aloud protocols in order to determine if other SRL processes are influenced by the experimental conditions.

It may be the case that some representations require assistance to learners in locating corresponding elements whereas others do not necessarily need to be scaffolded. For example, in the first page of the instructional content, one element which is scaffolded is the human heart. Almost all college students should know where the heart is located in the human body, so scaffolding may be unnecessary at this point. Determining the appropriate level of scaffolding is an endeavor which requires more investigation. The individual items on the multiple choice pretest and posttest could be mapped to the page of content where instructional content needed to answer that item appears. In this way, one could determine for which pages of content it is more essential to include attention guidance techniques. For example, one might predict that the pages which describe and depict the flow of blood through the heart, lungs, and body would require more support than a page that is merely talking about the functions of the circulatory system as a whole. In the latter case, it may not be necessary to even view the accompanying diagram to understand that the circulatory system is responsible for carrying blood and oxygen to all parts of the body.

Conclusions

This dissertation provides evidence for the effectiveness of integration scaffolding in facilitating learners' ability to integrate information from textual and pictorial representations. The success of integration scaffolding is brought about through guiding learners' attention to relevant areas in the diagrammatic representation. This promising finding suggests that alternative methods of circumventing the split-attention problem in hypermedia environments should include a mechanism for directing attention to corresponding elements within text and diagrams. The results support the two major models of text-picture integration (Mayer, 2005; Schnotz, 2005) as well as Cognitive Load Theory (Sweller et al., 1998). Within learning materials that utilize typed text and diagrams, learners' need to process verbal and pictorial information simultaneously in working memory can be supported through attention guidance features such as integration scaffolding.

References

Adobe Dreamweaver (Version CS4) [Computer Software]. (2008). San Jose, California: Adobe Systems Incorporated.

Ainsworth, S. (2008). How should we evaluate multimedia learning environments. In J. F. Rouet, R. Lowe, & W. Schnotz (Eds.), *Understanding Multimedia Comprehension.* New York: Springer.

Austin, K. A. (2009). Multimedia learning: Cognitive individual differences and display design techniques predict transfer learning with multimedia learning modules. *Computers and Education, 53*(4), 1339-1354.

Ayres, P. (2006). Impact of reducing intrinsic cognitive load on learning in a mathematical domain. *Applied Cognitive Psychology, 20*, 287-298.

Azevedo, R., & Cromley, J. G. (2004). Does training on self-regulated learning facilitate students' learning with hypermedia? *Journal of Educational Psychology*, *96*, 523–535.

Azevedo, R., Cromley, J. G., Moos, D. C., Greene, J. A., & Winters, F. I. (in press). Adaptive content and process scaffolding: The key to facilitating students' self-regulated learning with hypermedia. *Psychology Science Quarterly.*

Azevedo, R., Cromley, J. G., & Seibert, D. (2004). Does adaptive scaffolding facilitate students' ability to regulate their learning with hypermedia? *Contemporary Educational Psychology*, *29*(3), 344–370.

Azevedo, R., Cromley, J. G., Winters, F. I., Moos, D. C., & Greene, J. A. (2005). Adaptive human scaffolding facilitates adolescents' self-regulated learning with hypermedia. *Instructional Science (Special Issue on Scaffolding Self-Regulated*

Learning and Metacognition: Implications for the Design of Computer-Based Scaffolds), 33, 381–412.

Azevedo, R., Greene, J. A, & Moos, D. C. (2007). The effect of a human agent's external regulation upon college students' hypermedia learning. *Metacognition & Learning, 2*(2/3), 67-87.

Azevedo, R., Moos, D. C., Greene, J. A., Winters, F. I., & Cromley, J. G. (2008). Why is externally-regulated learning more effective than self-regulated learning with hypermedia? *Educational Technology Research & Development, 56*(1), 45-72.

Azevedo, R., Moos, D., Johnson, A., & Chauncey, A. (2010). Measuring cognitive and metacognitive regulatory processes used during hypermedia learning: Issues and challenges. *Educational Psychologist, 45*(4), 210-223.

Baddeley, A. D. (1986). *Working memory*. Oxford, England: Clarendon Press.

Baddeley, A. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417-423.

Bartholome, T., & Bromme, R. (2009). Coherence formation when learning from text and pictures: What kind of support for whom? *Journal of Educational Psychology, 101*(2), 282-293.

Berthold, K., & Renkl, A. (2009). Instructional aids to support a conceptual understanding of multiple representations. *Journal of Educational Psychology, 101*(1), 70-87.

Bodemer, D., & Faust, U. (2006). External and mental referencing of multiple representations. *Computers in Human Behavior, 22*, 27-42.

Brunken, R., Plass, J. L., & Leutner, D. (2003). Direct measurement of cognitive load in mutlimedia instruction. *Educational Psychologist*, *38*(1), 53-61.

Brunken, R., Steinbacher, S., Plass, J. L., & Leutner, D. (2002). Assessment of cognitive load in multimedia learning using dual-task methodology. *Experimental Psychology, 49*(2), 109-119.

Canham, M., & Hegarty, M. (2010). Effects of knowledge and display design on comprehension of complex graphics. *Learning and Instruction, 20*(2), 155-166.

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction*, *8*(4), 293-332.

Cierniak, G., Scheiter, K., & Gerjets, P. (2009). Explaining the split-attention effect: Is the reduction of extraneous cognitive load accompanied by an increase in germane cognitive load? *Computers in Human Behavior*, *25*, 315-324.

Ericsson, K. A. (2006). Protocol analysis and expert thought: Concurrent verbalizations of thinking during experts' performance on representative tasks. In K. A. Ericsson, N. Charness, P. J. Feltovich, & R. R. Hoffman (Eds.), *The Cambridge handbook of expertise and expert performance* (pp. 223-241). New York, NY: Cambridge University Press.

Ericsson, K. A., & Simon, H. A. (1993). *Protocol analysis; Verbal reports as data (revised edition)*. Cambridge, MA: Bradford books/MIT Press.

Gentner, D., & Stevens, A. L. (1983). *Mental Models.* Hillsdale, NJ: Lawrence Erlbaum.

Gerjets, P., Scheiter, K., Opfermann, M., Hesse, F. W., & Eysink, T. H. S. (2009). Learning with hypermedia: The influence of representational formats and different levels of learner control on performance and learning behavior. *Computers in Human Behavior*, *25*, 360-370.

Ginns, P. (2006). Integrating information: A meta-analysis of the spatial contiguity and temporal contiguity effects. *Learning and Instruction, 16*, 511-525.

Goldman, S. (2003). Learning in complex domains: When and why do multiple representations help? *Learning and Instruction, 13*, 239-244.

Hacker, D. J., Dunlosky, J., & Graesser, A. C. (2009). *Handbook of metacognition in education*. Mahwah, NJ: Erlbaum/Taylor & Francis.

Harp, S. F., & Mayer, R. E. (1998). How seductive details do their damage: A theory of cognitive interest in science learning. *Journal of Educational Psychology, 90*, 414-434.

Hegarty, M. (1992). Mental animation: Inferring motion from static displays of mechanical systems. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*(5), 1084-1102.

Hegarty, M., & Just, M. A. (1983). Constructing mental models of machines from text and diagrams. *Journal of Memory and Language*, *32*, 717-742.

Hegarty, M. Narayanan, N. H., & Freitas, P. (2002). Understanding machines from multimedia and hypermedia presentations. In J. Otero, A. C. Graesser, & J. Leon (Eds.). *The Psychology of Science Text Comprehension.* Mahwah, NJ: Lawrence Erlbaum Associates.

Hmelo-Silver, C. E., & Pfeffer, M. G. (2004). Comparing expert and novice understanding of a complex system from the perspective of structures, behaviors, and functions. *Cognitive Science, 28*, 127-138.

Huk, T., & Steinke, M. (2007). Learning cell biology with close-up views or connecting lines: Evidence for the structure mapping effect. *Computers in Human Behavior, 23*, 1089-1104.

Jamet, E., Gavota, M., & Quaireau, C. (2008). Attention guiding in multimedia learning. *Learning and Instruction, 18*, 135-145.

Jeung, H., Chandler, P., & Sweller, J. (1997). The role of visual indicators in dual sensory mode instruction. *Educational Psychology, 17*(3). 329-343.

Johnson-Laird, P. N. (1983). *Mental Models: Towards a Cognitive Science of Language, Inference, and Consciousness.* Cambridge: Cambridge University Press.

Kalguya, S., Chandler, P., & Sweller, J. (1999). Managing split-attention and redundancy in multimedia instruction. *Applied Cognitive Psychology, 13,* 351-371.

Kester, L., Kirschner, P., & van Merrienboer, J. J. G. (2005). The management of cognitive load during complex cognitive skill acquisition by means of computer-simulated problem solving. *British Journal of Educational Psychology, 75*, 71-85.

Mautone, P. D., & Mayer, R. E. (2001). Signaling as a cognitive guide in multimedia learning. *Journal of Educational Psychology, 93*(2) 377-389.

Mayer, R. E. (2005). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 31-48). New York, NY: Cambridge University Press.

Mayer, R. E. (2008). Applying the science of learning: Evidence-based principles for the design of multimedia instruction. *American Psychologist, 63*(8),760-769.

Mayer, R. E. (2009). *Multimedia Learning* (2nd ed). New York: Cambridge University Press.

Mayer, R. E., & Gallini, J. K. (1990). When is an illustration worth a thousand words? *Journal of Educational Psychology*, *82*(4), 715-726.

Mayer, R. E., Heiser, J., & Lonn, S. (2001). Cognitive constraints on multimedia learning: When presenting more material results in less understanding. *Journal of Educational Psychology, 93*(1), 187-198.

Mayer, R. E., Steinhoff, K., Bower, G., & Mars, R. (1995). A generative theory of textbook design: Using annotated illustrations to foster meaningful learning of science text. *Educational Technology Research and Development, 43*(1), 31-44.

Moos, D. C., & Azevedo, R. (2006). The role of goal structure in undergraduates' use of self-regulatory variables in two hypermedia learning tasks. *Journal of Educational Multimedia and Hypermedia*, *15*(1), 49–86.

Moreno, R., & Mayer, R. E. (1999). Cognitive principles of multimedia learning: The role of modality and contiguity. *Journal of Educational Psychology, 91*(2), 358-368.

Moreno, R., Reisslein, M., & Ozogul, G. (2010). Using virtual peers to guide visual attention during learning: A test of the persona hypothesis. *Journal of Media Psychology, 22*(2), 52-60.

Nelson, T. O., & Dunlosky, J. (1991). When people's judgments of learning (JOLs) are extremely accurate at predicting subsequent recall: The "delayed-JOL effect." *Psychological Science, 2*, 267-270.

Niederhauser, D. (2008). Educational hypertext research. In J. M. Spector, M. D. Merrill, J. van Merrienboer, & M. P. Driscoll (Eds.), *Handbook of research on* *educational communications and technology (3rd Ed.)* (pp. 199-210). New York: Lawrence Erlbaum Associates.

Norman, D. A. (1986). Cognitive Engineering. In D. A. Norman & S. W. Draper (Eds.), *User Centered System Design: New Perspectives on Human-Computer Interaction*. Hillsdale, NJ: Lawrence Erlbaum Associates

Ozcelik, E., Karakus, T., Kursun, E., & Cagiltay, K. (2009). An eye-tracking study of how color coding affects multimedia learning. *Computers & Education*, *53*, 445-453.

Paas, F., Renkl., A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist, 38*(1), 1-4.

Paas, F., Tuovinen, J. E., Tabbers, H., & van Gerven, P.W.M. (2003). Cognitive load measurement as a means to advance Cognitive Load Theory. *Educational Psychologist, 38*(1), 63-71.

Paas, F., & Van Merriënboer, J.J.G. (1994). Variability of worked examples and transfer of geometrical problem-solving skills: A cognitive-load approach. *Journal of Educational Psychology, 86*, 122-133.

Paivio, A. (1986). *Mental representations: A dual coding approach*. New York: Oxford University Press.

Pintrich, P. R. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts, P. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 451-502). San Diego, CA: Academic Press.

Rouet, J. F. (2009). Managing cognitive load during document-based learning. *Learning and Instruction, 19*(5), 445-450.

Scheiter, K., Gerjets, P., & Catrambone, R. (2006). Making the abstract concrete: Visualizing mathematical solution procedures. *Computers in Human Behavior, 22*, 9-25.

Schnotz, W. (2005). An integrated model of text and picture comprehension. In R. E. Mayer (ed.), *The Cambridge handbook of multimedia learning* (pp. 49-69). New York: Cambridge University Press.

Schnotz, W., & Bannert, M. (2003). Construction and interference in learning from multiple representation. *Learning and Instruction, 13*, 141-156.

Schnotz, W., & Kurschner, C. (2007). A reconsideration of cognitive load theory. *Educational Psychology Review, 19*, 469-508.

Seufert, T. (2003). Supporting coherence formation in learning from multiple representations. *Learning and Instruction, 13*, 227-237.

Seufert, T., & Brünken, R. (2006). Cognitive load and the format of instructional aids for coherence formation. *Applied Cognitive Psychology, 20*, 321-331.

Seufert, T., Schutze, M., & Brunken, R. (2009). Memory characteristics and modality in multimedia learning: An aptitude-treatment-interaction study. *Learning and Instruction, 19*, 28-42.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*, 257-285.

Sweller, J. (2005). Implications of cognitive load theory for multimedia learning. In R. E. Mayer (ed.), *The Cambridge handbook of multimedia learning* (pp. 19-30). New York, NY: Cambridge University Press.

Sweller, J., & Chandler, P. (1991). Evidence for cognitive load theory. *Cognition and Instruction, 8*(4), 351-362.

Sweller, J., Chandler, P., Tierney, P., & Cooper, M. (1990). Cognitive load and selective attention as factors in the structuring of technical material. *Journal of Experimental Psychology: General*, *119*, 176-192.

Sweller, J., van Merrienboer, J. J. G., & Paas, F. G. W. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10* (3), 1998.

Tabbers, H. K, Martens, R. L., & Van Merrienboer, J. J. G. (2001). The modality effect in multimedia instructions. In J. D. Moore & K. Stenning (Eds), *Proceedings of the 23rd annual conference of the Cognitive Science Society* (pp. 1024-1029). Mahwah, NJ: Lawrence Erlbaum Associates.

Tabbers, H. K., Martens, R. L., & van Merrienboer, J. J. G. (2004). Multimedia instructions and cognitive load theory: Effects of modality and cueing. *British Journal of Educational Psychology*, *74*, 71-81.

Tarmizi, R. A., & Sweller, J. (1988). Guidance during mathematical problem solving. *Journal of Educational Psychology*, *80*(4), 424-436.

Theide, K. W., & Dunlosky, J. (1994). Delaying students' metacognitive monitoring improves their accuracy in predicting their recognition perfromance. *Journal of Educational Psychology, 86*(2), 290-302.

Tobii Studio™ (Version 1.5) [Computer Software]. (2009). Stockholm, Sweden: Tobii Technology.

Tobii T60 [Apparatus]. (2009). Stockholm, Sweden: Tobii Technology.

Van Meter, P., Firetto, C., & Higley, K. (2007). *The integration of representations: A program of research for academic development.* Paper presented at the annual meeting of the American Educational Research Association, Chicago, IL.

Winne, P. H. (2001). Self-regulated learning viewed from models of information processing. In B. Zimmerman & D. Schunk (Eds.), *Self-regulated learning and academic achievement: Theoretical perspectives* (pp. 153-189). Mahwah, NJ: Erlbaum.

Winne, P.H., & Hadwin, A. (1998). Studying as self-regulated learning. In D.J. Hacker, J. Dunlosky, and A. Graesser (Eds.), *Metacognition in educational theory and practice (*pp. 277-304). Hillsdale, NJ: Erlbaum.

Winne, P.H., & Hadwin, A. (2008). The weave of motivation and self-regulated learning. In D. H. Schnunk & B. J. Zimmerman (Eds.), *Motivation and self-regulated learning: Theory, research and applications* (pp. 297-314). Mahwah, NJ: Erlbaum.

Winne, P. H., & Perry, N. E. (2000). Measuring self-regulated learning. In M. Boekaerts, P. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 531-566). San Diego, CA: Academic Press.

Winters, F. I., & Azevedo, R. (2005). High school students' regulation of learning during computer-based science inquiry. *Journal of Educational Computing Research*, *33*(2), 189–215.

Witherspoon, A.M., & Azevedo, R. (2008). The effectiveness of integration scaffolding techniques in learning with multiple external representations. In F. Maes & S.

Ainsworth (Eds.), *Exploiting the opportunities: Learning with textual, graphical, and multimodal representations* (pp. 157-161). Tilburg, The Netherlands: EARLI.

Zimmerman, B. (2000). Attaining self-regulation: A social cognitive perspective. In M. Boekaerts, P. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 13-39). San Diego, CA: Academic Press.

Zimmerman, B. (2008). Investigating self-regulation and motivation: Historical background, methodological developments, and future prospects. *American Educational Research Journal*, *45*(1), 166–183.

Appendix A: Texts and Diagrams from Hypermedia Learning Environment

Global Level Texts and Diagram

1) Introduction
   The circulatory system is made up of three major parts: the heart, blood vessels (arteries, veins, and capillaries), and blood. The heart is the muscle that pumps blood around the body through tubes called blood vessels. The heart, blood, and blood vessels work together to carry oxygen from the lungs to all the other tissues in the body and, in turn, carry waste products, predominantly carbon dioxide, back to the lungs where they are released into the air.

   The human heart is shaped like an upside-down pear and is located slightly to the left of center inside the chest cavity. About the size of a closed fist, the heart is made of muscle tissue that contracts rhythmically to propel blood to all parts of the body. The muscle rests only for a fraction of a second between beats. The heart must beat ceaselessly because the body's tissues—especially the brain and the heart itself—depend on a constant supply of oxygen and nutrients delivered by the flowing blood. If the heart stops pumping blood for more than a few minutes, death will result.

2) Blood Vessels & Blood Cells
   There are three types of blood vessels: arteries, veins, and capillaries. Arteries carry blood away from the heart. Veins carry blood toward the heart. Capillaries are the tiny tubes connecting the arteries and the veins where oxygen and nutrients can move from the blood into body organs, and where wastes from body organs move into the blood.

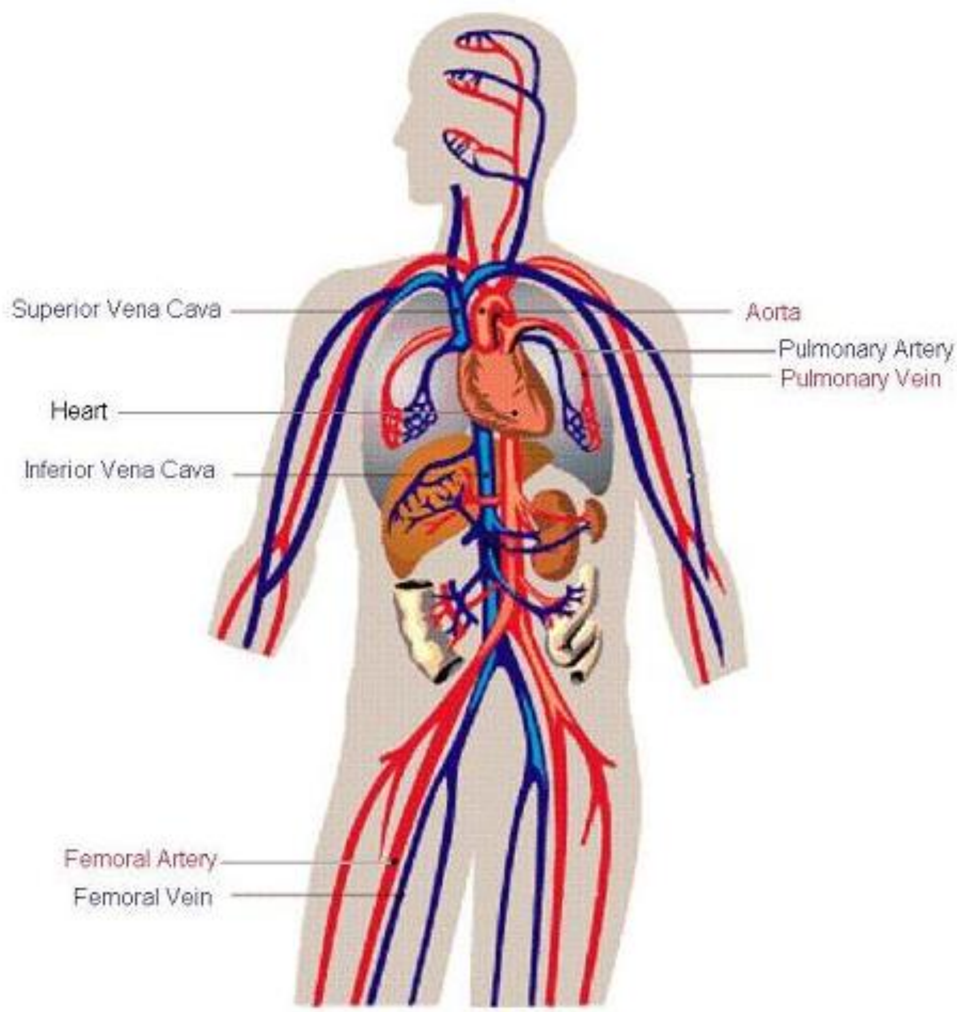
   There are also three major types of blood cells: red blood cells, white blood cells, and platelets. All three are carried through blood vessels in a liquid called plasma. Red blood cells make up the majority of the cells in the blood and are responsible for carrying oxygen to the tissues of the body and then carbon dioxide away. White blood cells play a vital role in the body's immune system—the primary defense mechanism against invading bacteria, viruses, fungi, and parasites. They often accomplish this goal through direct attack, which usually involves identifying the invading organism as foreign, attaching to it, and then destroying it. The smallest cells in the blood are the platelets, which are designed for a single purpose—to begin the process of coagulation, or forming a clot, whenever a blood vessel is broken.

3) Two Circulatory Systems
   The blood in the circulatory system moves around the body and through the heart in a continuous cycle. There are two loops that are connected like a figure 8. These two loops are named the systemic circulation and the pulmonary circulation. The systemic circulation carries oxygenated blood from the heart to all the tissues in the body except the lungs and returns deoxygenated blood carrying waste products, such as carbon dioxide, back to the heart. The pulmonary circulation carries this spent blood from the heart to the lungs. In the lungs, the blood releases its carbon dioxide and absorbs oxygen. The oxygenated blood then returns to the heart before transferring to the systemic circulation.

4) Systemic & Pulmonary Circulation

Systemic circulation begins when oxygenated blood is pumped from the heart, through the aorta to the arteries (such as the femoral artery) in the body. These arteries become smaller, eventually forming the capillaries, where oxygen is transferred to the tissues of the body. At the same time, carbon dioxide from the tissues enters the blood in the capillaries. This deoxygenated blood then goes from the capillaries to the veins (such as the femoral vein) in the body and returns to the heart through the superior and inferior vena cava. Then pulmonary circulation begins.

Pulmonary circulation carries the deoxygenated blood from the heart to the lungs through the pulmonary arteries. In the lungs, the blood picks up oxygen and drops off carbon dioxide. The oxygenated blood then returns to the heart through the pulmonary veins and is pumped from the heart, beginning systemic circulation once again.



Intermediate Level Texts and Diagram

1) Components of the Heart
The human heart is divided into four chambers: the right atrium, the right ventricle, the left atrium, and the left ventricle. The walls of these chambers are made of a special muscle called myocardium, which squeezes to pump blood throughout the body. The heart also has four valves, which are responsible for keeping blood from flowing backward within the heart. Two valves are located between the atria and ventricles: the tricuspid valve and mitral valve. The other two valves are located between the ventricles and the arteries: the pulmonary valve and the aortic valve.

2) Cycle of Blood Flow 1
Blood moves through the heart and body in a cycle. If we start at the right side of the heart, the cycle begins when:

1) Blood from the body comes into the heart from the two largest veins in the body, the inferior vena cava and the superior vena cava. This blood is not carrying oxygen because it just dropped off oxygen in the body's organs and muscles. This "oxygen-poor" (deoxygenated) blood flows from both of the vena cavas into the right atrium.

2) Once the right atrium is full of blood, the atrium squeezes and pushes blood through the tricuspid valve into the right ventricle.

3) The tricuspid valve then closes to keep blood from leaking back into the right atrium.

4) Once the right ventricle is full of blood, the ventricle squeezes, and pushes blood through the pulmonary valve into the pulmonary arteries (pulmonary means "lungs".)

5) Then the pulmonary valve closes to keep blood from leaking back into the right ventricle.

3) Cycle of Blood Flow 2
6) The blood moves through the pulmonary arteries to the lungs to pick up the oxygen that we breathe in. One of the pulmonary arteries goes to the left lung and the other pulmonary artery goes to the right lung.

7) In the lungs, the main pulmonary arteries split into many tiny arteries throughout the lungs. The arteries become smaller, eventually forming the capillaries. The oxygen in the lungs moves through the capillary walls into the blood where it is picked up by red blood cells. In the same way, carbon dioxide leaves the blood and is breathed out of the lungs.

8) This oxygenated blood heads back to the heart in both right and left pulmonary veins.

9) The pulmonary veins then carry the blood into the left atrium of the heart.

10) Once the left atrium is full of blood, the atrium squeezes and pushes blood through the mitral valve into the left ventricle.

4) Cycle of Blood Flow 3

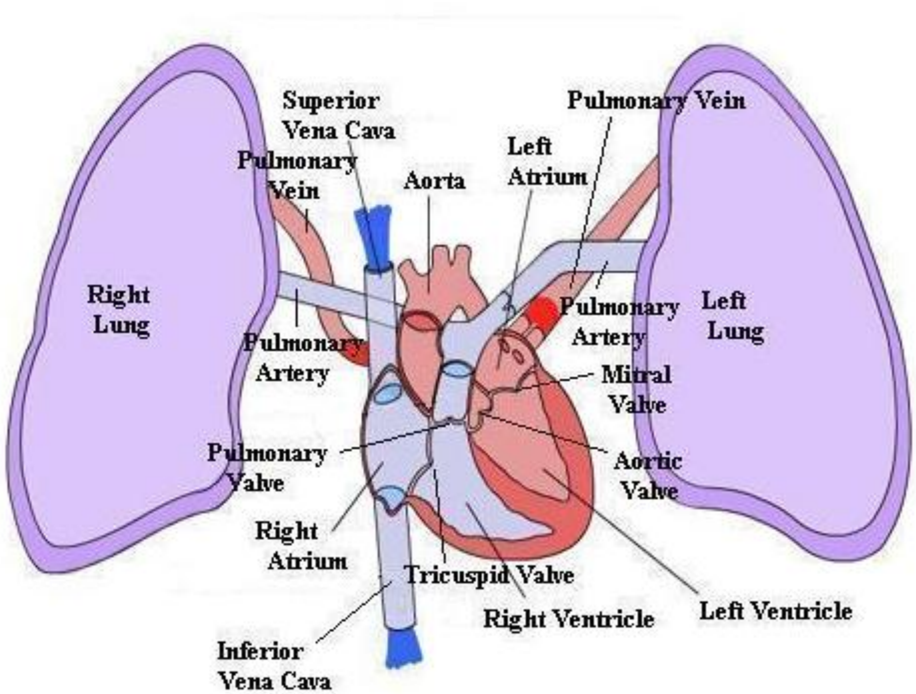
11) The mitral valve then closes to keep blood from leaking back into the left atrium.

12) Once the left ventricle is full of blood, the ventricle squeezes very hard, and pushes blood through the aortic valve into the aorta. The aorta, which takes blood to all parts of the body, is the largest artery in the body.

13) The aortic valve then closes to keep blood from leaking back into the left ventricle.

14) The aorta splits into many tiny arteries throughout the body. These arteries grow smaller until they become capillaries. Once blood is in the capillaries, the red blood cells release the oxygen they have carried from the lungs, and the oxygen moves through the capillary walls and into the organs and muscles that need it. Carbon dioxide, from the muscles and tissues, moves in the opposite direction – into the blood to be carried back to the lungs as waste.

15) This deoxygenated blood heads back to the heart in veins. These veins from all over the body join up with the superior and inferior vena cava, and the cycle begins again.



Intermediate Level Texts and Diagram

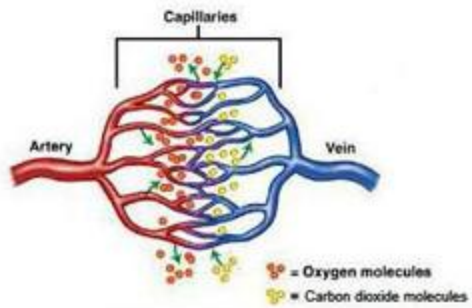
1) Diffusion
   The exchange of gases (oxygen and carbon dioxide) is driven by diffusion, which is the movement of molecules from a highly concentrated area to a lower concentrated area. This exchange occurs at the capillary level both in the tissues within the body as well as in the lungs. Capillaries are tiny tubes that connect the arteries to the veins. They are the smallest of blood vessels and can only be seen by microscope. Ten capillaries lying side by side are thinner than a single human hair. The walls of capillaries are very thin and gases and liquids from the blood and body can move across the walls easily.

2) Oxygen & Carbon Dioxide Exchange
   In the blood, each red blood cell has a molecule of hemoglobin, which is a special molecule that holds oxygen. In the lungs, oxygen enters the blood by crossing the capillary walls and carbon dioxide leaves the blood through the same process. In contrast, when blood is delivered to the capillaries within the tissues in the rest of the body, oxygen leaves the blood by crossing the capillary walls and carbon dioxide enters the blood. This is why we refer to blood traveling from the lungs to the tissues of the body as oxygenated, and blood traveling from the tissues to the lungs as deoxygenated.

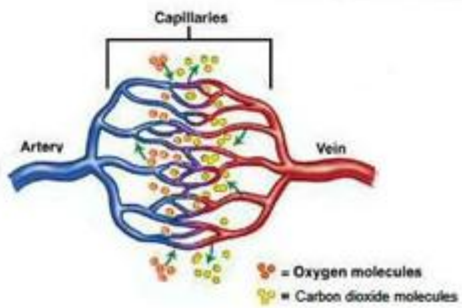
3) Gas Exchange at Tissue
   Our body's cells use oxygen and nutrients to create energy. This process is called metabolism. Metabolism produces water and carbon dioxide as by-products. The circulatory system works to deliver oxygen and nutrients to cells and to carry away waste products such as carbon dioxide. At the tissue level within the body, capillaries running throughout the tissues deliver the oxygen and nutrients to the cells. After blood has left the left side of the heart, it travels in arteries to these capillaries, where oxygen molecules diffuse across the capillary walls to the tissues and carbon dioxide molecules diffuse in the opposite direction into the blood. After delivering the oxygen and nutrients to the body's tissues, the deoxygenated blood returns (in veins) to the heart and then lungs, where carbon dioxide is expelled from the body.

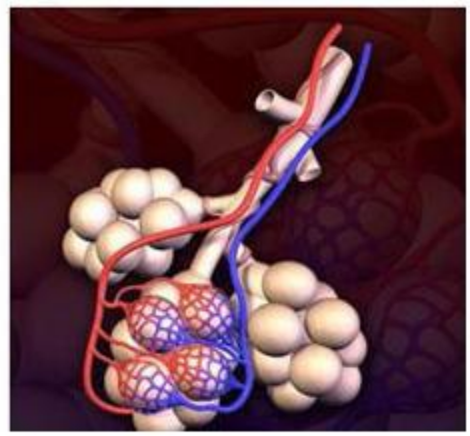
4) Gas Exchange in Lungs
   The gas exchange that occurs in the lungs is referred to as pulmonary gas exchange. This is accomplished at the alveoli (air sacs) in the lungs. Blood moves to the capillaries in the lungs through pulmonary arteries. Oxygen moves from the alveoli (high oxygen concentration) to the blood (lower oxygen concentration, due to the continuous consumption of oxygen in the body). Air entering the lungs contains about 21 percent oxygen and 0.04 percent carbon dioxide. Air leaving the lungs contains about 14 percent oxygen and about 4.4 percent carbon dioxide. Once the blood has been oxygenated in the lungs, it then returns to the left side of the heart through the pulmonary veins. These veins are one of few exceptions to the rule that oxygenated blood travels in arteries.

Capillary bed at tissue (in the body)



Capillary bed at alveoli (inside lung)

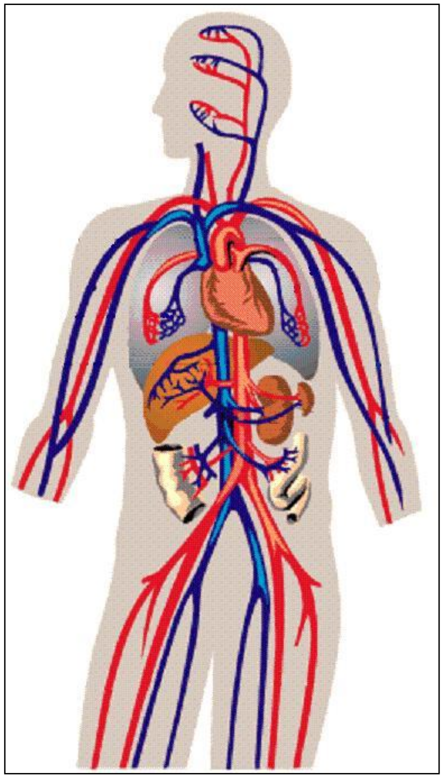


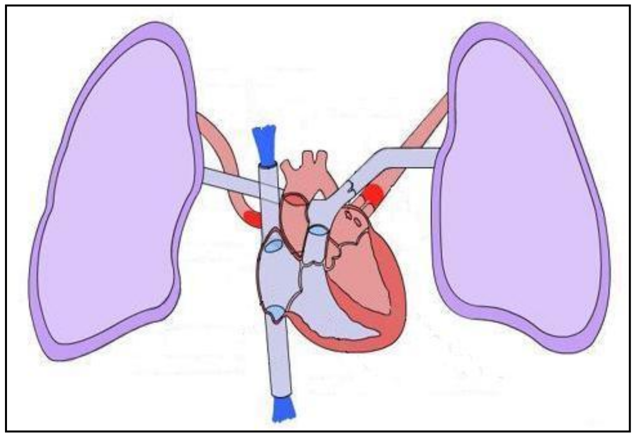


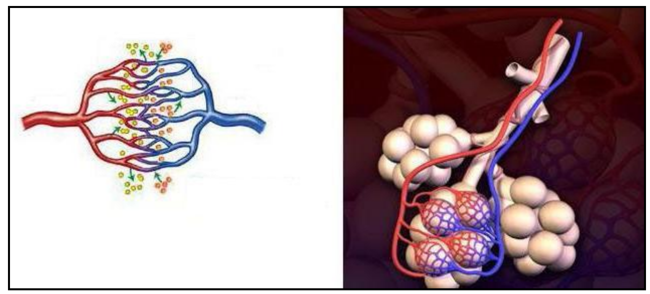
Appendix B: Diagram Interpretation Task

Circulatory System Diagram Task

On the following page are three diagrams of the circulatory system. Use these three diagrams in any way you would like to describe your understanding of the circulatory system. You can draw on any of the diagrams that you would like to during this task, using the pens provided. **PLEASE TELL ME EVERYTHING YOU CAN ABOUT THE CIRCULATORY SYSTEM.** Be sure to include all the parts and their purpose, explain how they work both individually and together, and also explain how they contribute to the healthy functioning of the body. If you want to talk about a particular component of the system, you can either write the name of that component on the sheet or just point to it with your pen while referring to it.







Appendix C: Multiple Choice Test

CIRCULATORY SYSTEM MULTIPLE CHOICE TEST

INSTRUCTIONS: CIRCLE THE RESPONSE THAT BEST ANSWERS THE QUESTIONS.
CHOOSE ONE AND ONLY ONE ANSWER FOR EACH QUESTION.
(24 POINTS)

1. What is one of the main purposes of the human heart?
   A. The source of oxygen for blood
   B. Cleans blood of waste products
   C. Allows us to feel emotions
   D. Moves blood around the body

2. Where does blood travel?
   A. Only between the heart and the brain
   B. Only inside the heart
   C. Around our body, but not our heart
   D. Around our whole body

3. After blood flows into the right ventricle, it goes through the ________ valve into the ________.
   A. Pulmonary…pulmonary veins
   B. Aortic…aorta
   C. Aortic…arteries
   D. Pulmonary…pulmonary arteries

4. What is one of the main purposes of the human circulatory system?
   A. Gives oxygen and nutrients to parts of the body
   B. Allows us to breathe
   C. Makes hormones
   D. Breaks down nutrients into smaller components

5. After blood flows into the left ventricle, it goes through the ________ valve into the ________.
   A. Mitral…right atrium
   B. Tricuspid…left atrium
   C. Pulmonary…aorta
   D. Aortic…aorta

6. Choose the BEST description of blood movement:
   A. Blood travels by moving freely through the spaces (interstitial fluid) between all body cells
   B. Blood travels in tubes around the body
   C. Blood travels by moving through cells in the body
   D. Blood travels by moving through veins, arteries, and capillaries in the body

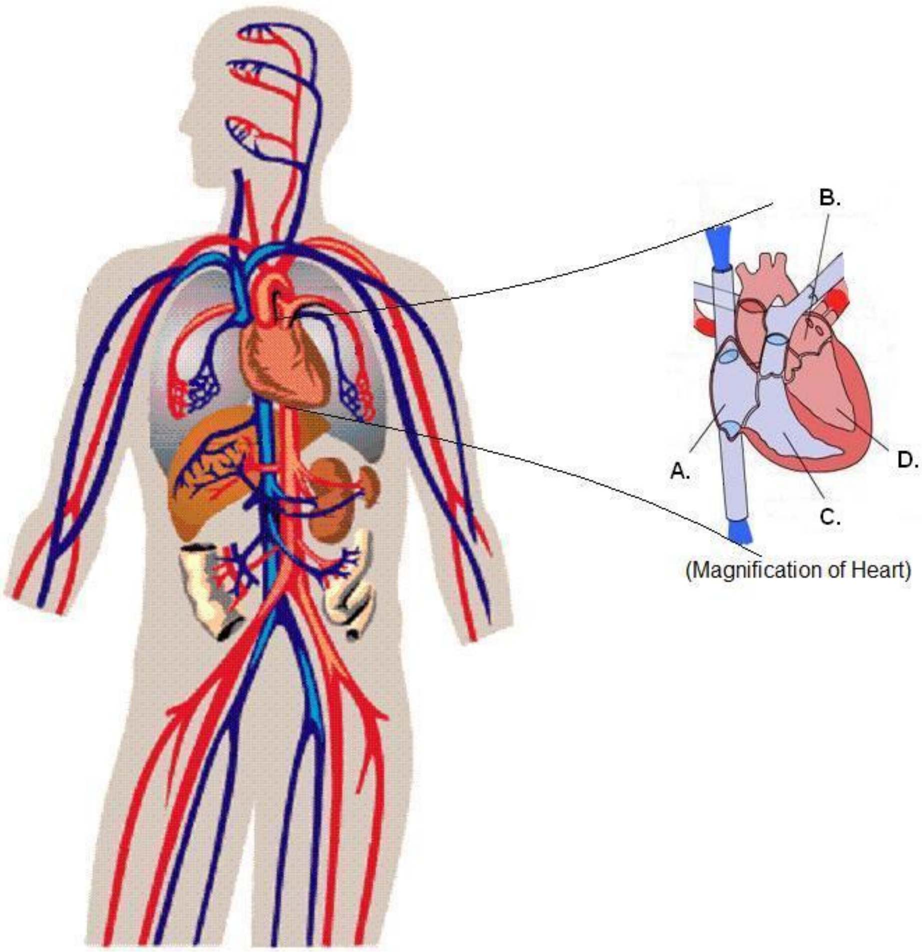
7. What are the three types of blood vessels?
    A. Heart, lungs, brain
    B. Superior vena cava, inferior vena cava, and aorta
    C. Arteries, veins, capillaries
    D. Small, medium, large

8. Circle the statement that is *most* true:
    A. Blood picks up oxygen in the lungs
    B. Blood picks up oxygen in the veins
    C. Blood picks up oxygen in the heart
    D. Blood does not pick up oxygen

9. After blood flows into the tissues of the body (except the lungs), it goes to the ________.
    A. Arteries
    B. Veins
    C. Left ventricle
    D. Left atrium

10. Circle the statement that you think is MOST true about the circulatory system:
    A. There is only one system of circulation that takes blood all around our body in one big loop
    B. There are two separate systems of circulation, one which travels on the right side of the body, and one which travels on the left side of the body
    C. There are three systems of circulation, one which takes blood to the brain and upper body, one which takes blood to the heart and middle body, and one which takes blood to the lower body
    D. There are two separate systems of circulation, one which goes from the heart to the body and then back to the heart, and one which goes from the heart to the lungs and back to the heart

Please use the accompanying diagram to answer the next two questions:



11. When blood leaves the "C" part of the heart, it:
    A. Goes out to the body then to "A"
    B. Goes out to the lungs, then back to "B"
    C. Goes to the "A" part of the heart
    D. Goes to the "D" part of the heart

12. The path of blood through the heart and body is BEST represented by:
    A. A →C→B→ D → Body → A … repeats
    B. A → B → D → C → Body → Lungs → A … repeats
    C. A → C → Lungs → B → D → Body → A … repeats
    D. C → D → B → A → Body → Lungs → C … repeats

13. Blood flowing in the pulmonary veins is heading to which body part?
    A. Heart
    B. Liver
    C. Lungs
    D. Kidneys

14. Blood enters the heart through the ________.
    A. Aorta
    B. Superior and inferior vena cava
    C. Arteries
    D. Pulmonary valve

15. What would occur if the mitral valve stopped working?
    A. The left atrium would not be able to fill with blood and would therefore not be able to squeeze and push blood into the left ventricle
    B. The left atrium would be able to squeeze blood into the left ventricle, but the blood would leak back into the left atrium, and the left ventricle would not be able to squeeze and push blood into the aorta
    C. The left ventricle would be able to fill with blood, and would be able to squeeze the blood into the aorta, but the left atrium would not be able to fill with blood
    D. The left ventricle would not be able to fill with blood and would therefore not be able to squeeze and push blood into the left atrium

16. Circle the path that BEST represents how the blood moves throughout the body:
    A. Body → Heart → Body → Heart → Body … repeats
    B. Body → Heart → Lungs → Heart → Body … repeats
    C. Body → Lungs → Heart → Body … repeats
    D. Body → Heart → Lungs → Body → … repeats

17. Hemoglobin carries ________ from the lungs to take to the cells in the body. It then reverses its function and picks up ________ to take to the lungs.
    A. Carbon dioxide…oxygen
    B. Carbon dioxide…nitrogen
    C. Oxygen…carbon dioxide
    D. Oxygen…nitrogen

18. After blood flows into the aorta, it goes to the ________.
    A. Arteries
    B. Veins
    C. Right ventricle
    D. Right atrium

19. After blood flows into the left atrium, it goes through the ________ valve into the ________.
    A. Mitral, right atrium
    B. Mitral, left ventricle
    C. Tricuspid, right atrium
    D. Tricuspid, left ventricle

20. What is the ultimate purpose for delivering oxygen and nutrients to the parts of the body?
    A. The body's cells use the oxygen and nutrients to create hormones
    B. The body's cells use the oxygen and nutrients for metabolism
    C. The body's cells use the oxygen and nutrients to reduce carbon dioxide levels
    D. The body's cells use the oxygen and nutrients to create more oxygen

21. Blood flowing in the pulmonary arteries is heading to which body part?
    A. Heart
    B. Liver
    C. Lungs
    D. Kidneys

22. What is the process that allows oxygen and nutrients to cross the capillary walls?
    A. Convection
    B. Metabolism
    C. Oxidation
    D. Diffusion

23. After blood flows into the right atrium, it goes through the ________ valve into the ________.
    A. Mitral, right ventricle
    B. Tricuspid, right ventricle
    C. Mitral, left ventricle
    D. Tricuspid, left ventricle

24. What is the body part within the lungs which contains oxygen to be delivered to the capillaries?
    A. Alveoli
    B. Ventricles
    C. Hemoglobin
    D. Atria

Appendix D: Subjective Cognitive Load Measure (adapted from Cierniak, Scheiter, &Gerjets, 2009)

Answer the following questions by circling the option which best describes your learning session.

How difficult was the learning material for you?

1 – Not at all 2 – Just a little bit 3 – somewhat 4 – pretty much 5 – very 6 - extremely

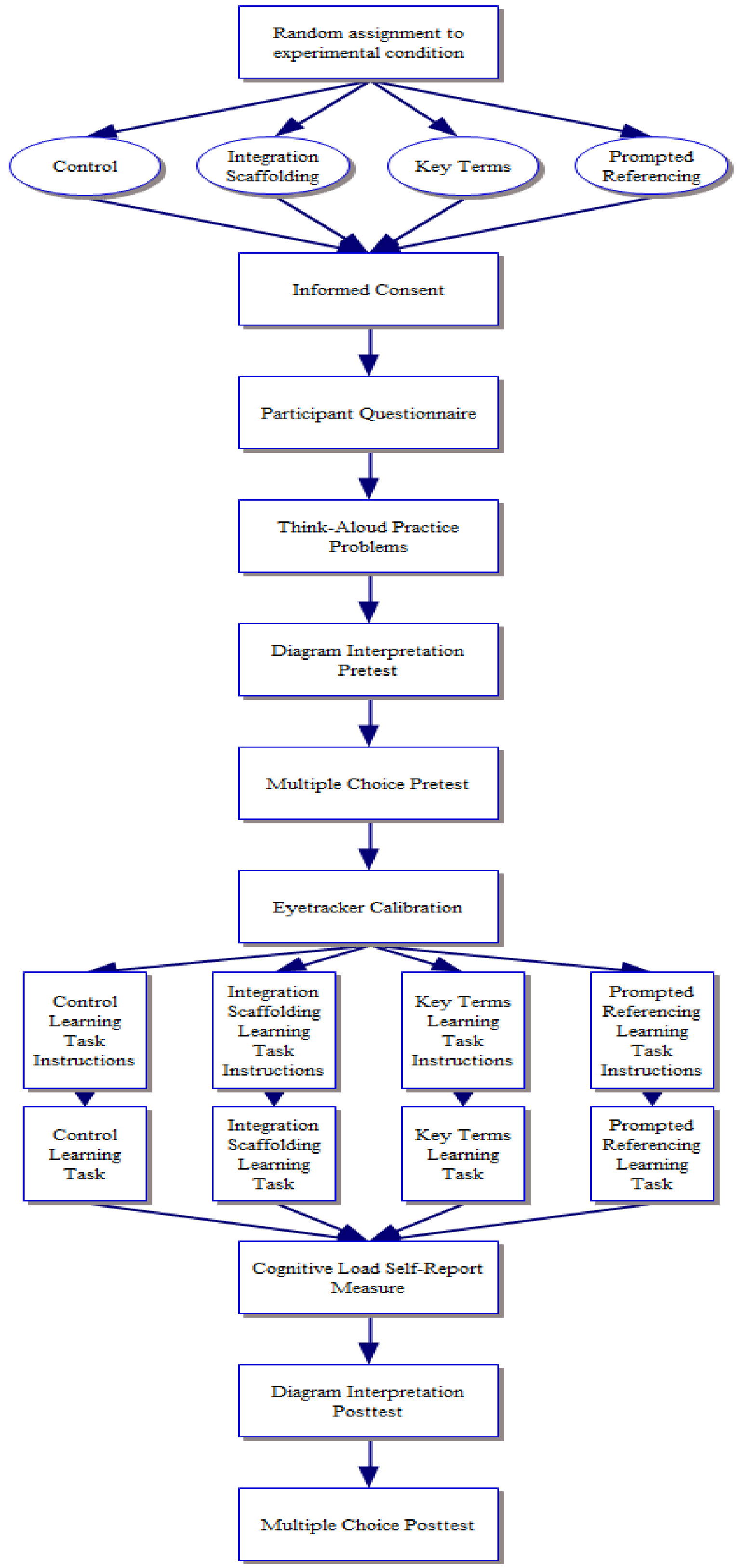
How difficult was it for you to learn with the material?

1 – Not at all 2 – Just a little bit 3 – somewhat 4 – pretty much 5 – very 6 - extremely

How much did you concentrate during learning?

1 – Not at all 2 – Just a little bit 3 – somewhat 4 – pretty much 5 – very 6 - extremely

Appendix E: Experimental Procedure



Appendix F: Learning Task Instructions

Instructions for control condition:

You are being presented with a computer-based learning environment, which contains textual information and static diagrams of the circulatory system. We are trying to learn more about how students learn from computer-based learning environments**. *Your task is to learn all you can about the human circulatory system in 20 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.*** In order for us to understand how you learn about the circulatory system, we also ask you to "think aloud" continuously while you are learning in this environment. Say everything you are thinking and doing. I'll be here in case anything goes wrong with the computer or the equipment. ***In this computer-based learning environments are texts and diagrams about the circulatory system. Please read the text and inspect the diagrams in whichever way you see fit.***Please remember that it is very important to say everything that you are thinking and doing while you are working on this task.

Instructions for integration scaffolding condition:

You are being presented with a computer-based learning environment, which contains textual information and static diagrams of the circulatory system. We are trying to learn more about how students learn from computer-based learning environments**. *Your task is to learn all you can about the human circulatory system in 20 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.*** In order for us to understand how you learn about the circulatory system, we also ask you to "think aloud" continuously while you are learning in this environment. Say everything you are thinking and doing. I'll be here in case anything goes wrong with the computer or the equipment. ***In this computer-based learning environment are texts and diagrams about the circulatory system. Certain words appear in blue, underlined. These words, when scrolled over, will highlight certain parts of the diagram relevant to what you are reading (For as long as your mouse is over these words). While you are reading the text, you can mouse over each underlined term and inspect the diagram***. Please remember that it is very important to say everything that you are thinking and doing while you are working on this task.

Instructions for key terms condition:

You are being presented with a computer-based learning environment, which contains textual information and static diagrams of the circulatory system. We are trying to learn more about how students learn from computer-based learning environments***. Your task is to learn all you can about the human circulatory system in 20 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.*** In order for us to understand how you learn about the circulatory system, we also ask you to "think aloud" continuously while you are learning in this environment. Say everything you are thinking and doing. I'll be here in case anything goes wrong with the computer or the equipment. ***In this computer-based learning environment are texts and diagrams about the circulatory system. Certain words appear in blue, underlined. These highlighted words indicate particularly important key terms within the text.*** Please remember that it is very important to say everything that you are thinking and doing while you are working on this task.

Instructions for prompted referencing condition:

You are being presented with a computer-based learning environment, which contains textual information and static diagrams of the circulatory system. We are trying to learn more about how students learn from computer-based learning environments***. Your task is to learn all you can about the human circulatory system in 20 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.*** In order for us to understand how you learn about the circulatory system, we also ask you to "think aloud" continuously while you are learning in this environment. Say everything you are thinking and doing. I'll be here in case anything goes wrong with the computer or the equipment. ***In this computer-based learning environment are texts and diagrams about the circulatory system. At certain points within the text, you will see instructions to reference (look at) the diagram. While you are reading the text, you can inspect the diagram at these points within the text.*** Please remember that it is very important to say everything that you are thinking and doing while you are working on this task.

Appendix G: IRB Approval Page

THE UNIVERSITY OF MEMPHIS

Institutional Review Board

To: Amy Witherspoon
Psychology

From: Chair, Institutional Review Board
for the Protection of Human Subjects
Administration 315

Subject: Investigating different components of integration scaffolding in hypermedia learning (E10-124)

Approval Date: December 22, 2009

This is to notify you that the Institutional Review Board has designated the above referenced protocol as exempt from the full federal regulations. This project was reviewed in accordance with all applicable statutes and regulations as well as ethical principles.

When the project is finished or terminated, please complete the attached Notice of Completion and send to the Board in Administration 315.

Approval for this protocol does not expire. However, any change to the protocol must be reviewed and approved by the board prior to implementing the change.

Chair, Institutional Review Board
The University of Memphis

Appendix H: Diagram Interpretation Scoring Rubric

Any statements directly referring to the circulatory system will be coded according to the following categories. Two points (2) will be assigned if the statement is completely correct, one point (1) will be assigned if the statement is partially correct (e.g. identifying the right atrium as the left atrium), and a zero (0) will be assigned if the statement is completely incorrect.

Structure: Participant indicates (through pointing or writing label on test) the correct location of one of the components of the system, or describes the structural organization of components of the system.
Ex. These are the pulmonary veins.
And it has the heart and the arteries running out of it.
The heart has four chambers.

Function: Participant states (or writes) the purpose of a particular structure within the system
Note: Function statements will often also indicate the location, but since this is a deeper level of explanation than location statements, it will only be coded as 'function'
Ex. [the lungs] which supply the blood with oxygen
And then you also have in the heart, various valves that actually prevent blood from travelling backwards.

Behavior: Participant states the underlying mechanism responsible for the functioning of the component.
Note: Again, behavior statements might include reference to either the location or function of the component, but these will only be coded as 'behavior' statements as this is the deepest level of explanation.
Ex. And how they're diffusing the nutrients, they uh, diffuse in and out of the capillary walls. Cuz the capillary walls are thin.

Flow: Participant states the path of blood/food flow through the system.
Note: Flow statements are often accompanied by gestures indicating location of components, but only 'flow' is coded in these circumstances.
Ex. /The heart pumps blood through the arteries/And they travel, the blood travels throughout your whole body/And then it returns back to the heart/ - 3 separate flow statements
Um, these two over here, these are the veins, which lead to the heart.

Appendix I: Descriptions and examples of eye-tracking measures

Measure	Formula	Example (see figures in table on next page)
Measures of search time/attention to irrelevant diagrammatic information		
Average search time for relevant information	Σ (# seconds searching)/# of relevant components viewed	
Irrelevant diagram fixation duration	Σ (diagram fixation durations) - Σ (relevant diagram fixation durations)	1184 - 651 = 533
Proportional irrelevant diagram fixation duration	Irrelevant diagram fixation duration/ Σ (diagram fixation durations)	533/1184 = 0.45
Irrelevant diagram fixation count	Σ (diagram fixations) - Σ (relevant diagram fixations)	2960 - 1628 = 1332
Proportional irrelevant diagram fixation count	Irrelevant diagram fixation count / Σ (diagram fixations)	1332/2960 = 0.45
Measures of attention to relevant diagram information		
Relevant diagram fixation duration	Σ (relevant diagram fixation durations)	651
Proportional relevant diagram fixation duration	Relevant diagram fixation duration/ Σ (diagram fixation durations)	651/1184 = 0.55
Relevant diagram fixation count	Σ (relevant diagram fixations)	1628
Proportional relevant diagram fixation count	Relevant diagram fixation count / Σ (diagram fixations)	1628/2960 = 0.55

	Page												
	1	2	3	4	5	6	7	8	9	10	11	12	Total
Total diagram fixations (*n*)	79	105	98	309	452	132	453	224	210	467	88	343	2960
Total diagram fixation duration (*secs*)	32	42	39	124	181	53	181	90	84	187	35	137	1184
Relevant diagram fixations (*n*)	24	0	44	260	450	30	43	132	10	232	80	323	1628
Relevant diagram fixation duration (*secs*)	10	0	18	104	180	12	17	53	4	93	32	129	651
Irrelevant diagram fixations (*n*)	55	105	54	49	2	102	410	92	200	235	8	20	1332
Irrelevant diagram fixation duration (*secs*)	22	42	21	20	1	41	164	37	80	94	3	8	533

Appendix J

Classes, Descriptions, and Examples of the Variables Used to Code Learners' Self-Regulatory Behavior (Based on Azevedo, Cromley, & Seibert 2004)

Variable [Abbreviation]	Description[1]	Student Example
Planning		
Planning [PLAN]	Stating two or more learning goals	"First, I want to learn about the different parts of the heart, and then the blood vessels."
Prior Knowledge Activation [PKA]	Searching memory for relevant prior knowledge either before beginning performance of a task or during task performance	"*Gamma globulin is composed of tens of thousands of unique antibody molecules.* I think they, um, they are like part of the immune system."
Recycle Goal in Working Memory [RGWM]	Restating the goal (e.g., question or parts of a question) in working memory	"I need to learn about all the parts and their purposes…"
Sub-Goal [SG]	Articulating a specific sub-goal that is relevant to the experiment-provided overall goal	"I want to learn more about plasma. I'm going to click on that."
Time and effort planning [TEP]	Attempts to intentionally control behavior	"I'm skipping over that section since 45 minutes is too short to get into all the details."
Monitoring		
Content Evaluation [CE] (+ or -)	Stating that just-seen text, diagram, or video is either relevant (or irrelevant)	[Learner reads about red blood cells] "This is just was I was looking for."
Expectation of adequacy of content [EAC] (+ or -)	Expecting that a certain content (e.g., section of text, diagram, video) will be adequate (or inadequate) given the current goal	"I'm going to actually look on the picture because that will help me understand"
Evaluate content as answer to goal [ECAG]	Statement that what was just read and/or seen meets a goal or sub-goal	[Learner reads text]… "So I think that's the answer to this question."
Feeling of Knowing [FOK] (+ or -)	Stating that there is an awareness of having (or having not) read or learned something in the past and having some understanding of it	"Oh, I already read that."

[1] All codes refer to what was recorded from the think-aloud protocols and video analysis

Variable [Abbreviation]	Description	Student Example
Judgment of Learning [JOL] (+ or -)	Indicating that there is (or is not) an understanding of what was just read/seen	"Okay, this makes sense."
Monitor Progress Toward Goals [MPTG]	Assessing whether previously-set goal has been met	"Those were our goals..I accomplished them."
Monitor Use of Strategies [MUS]	Commenting on usefulness of strategy	"Yeah, drawing really helped me understand how blood flow throughout the heart."
Self-questioning [SQ]	Posing a question and rereading to improve understanding of the content	Learner spends time reading text and then states, "What do I know from this?" and reviews the same content.
Time Monitoring [TM]	Referring to the number of minutes remaining	"There are a few seconds left"
Strategy Use		
Coordination of Information Sources [COIS]	Coordinating multiple representations (e.g., drawing and notes)	"I'm going to put that [text] together with the diagram."
Scaffolded Coordination of Information Sources [SCOIS]	Coordinating multiple representations using integration scaffolding interface element or following prompt to reference diagram	"*Goes through the mitral valve*.. Which is there."
Draw [DRAW]	Making a drawing or diagram to assist in learning	"…I'm trying to draw the diagram as best as possible."
Inferences [INF] (+ or -)	Drawing a conclusion based on two or more pieces of information that were read within the same paragraph in the learning materials.	"*Hypertension is elevated blood pressure, develops when the* blood- *body's blood vessels narrow, causing the heart to pump harder,* Which I'm guessing could cause a heart attack."
Knowledge Elaboration [KE]	Elaborating on what was just read, seen, or heard with prior knowledge	"*Heat dissipates through the skin, effectively lowering the temperature.* Like a car radiator."
Memorization [MEM]	Memorizing text, diagram, etc.	"I'm going to try to memorize this picture."
Mnemonic [MNEM]	Using a verbal or visual memory technique to remember content	"Arteries—A for away."
Preview [PREV]	Learner reads headings or subheadings either in text or headings of diagrams/video	"Systemic circulation, pulmonary circulation, additional functions, blood pressure…"
Re-reading [RR]	Re-reading a section of the learning environment.	"I'm reading this again."

Variable [Abbreviation]	Description	Student Example
Review Notes [RN]	Reviewing notes	"Let me read over these notes now."
Summarization [SUM] (+ or -)	Verbally restating what was just read, inspected, or heard in the environment	"This says that white blood cells are involved in destroying foreign bodies."
Taking Notes [TN]	Writing down information	"I'm going to write that under heart."
Task Difficulty and Demands		
Help Seeking Behavior [HSB]	Seeking assistance regarding either the adequacy of their understanding or their learning behavior, regardless of whether the instructions indicate that the experimenter/tutor will provide assistance	"Do you want me to give a more detailed answer?"
Task Difficulty [TD]	Indicating one of the following: (1) the task is either easy or difficult, (2) the questions are either simple or difficult, (3) using the hypermedia environment is more difficult than using a book	"This is harder than reading a book."
Motivation		
Interest statement [INT] (+ or -)	Indicating a certain level of interest in the task or in the content domain of the task	"This stuff is interesting."
Affect statement [AFF] (+ or -)	Indicating a certain valence of affect in regards to the task or content of the task	"That makes me sad."
No Code [NC]	Learner provides little revealing information about cognitive processing in a statement	"Um, yeah, let's see."