Differences in the Use of Macro-level Self-Regulated Learning Processes between Students that Gain Declarative Knowledge and Students that Gain Conceptual Understanding about Complex Science Topics

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Abstract

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(Under the Direction of Jeffrey A. Greene)

Learning complex science topics is an important part of students' education. Learning these complex topics is difficult, and students often fail to gain a conceptual understanding of them. Research shows that the use of hypermedia based learning environments can enhance students' ability to learn complex science topics. However, the use of hypermedia as a learning tool does not always improve students' learning. Additional research has shown that the use of self-regulated learning (SRL) processes enhances students' ability to reach a conceptual understanding of complex topics with hypermedia. In this study, to improve understanding of self-regulated learning with hypermedia, I examined what differentiates students that gain conceptual understanding from those that only gain declarative knowledge about a complex science topic. Specifically, I examined differences in the frequency of students' use of macro-level SRL processes. After completing the analysis, no statistically significant differences were found in the frequency participants in the conceptual understanding group employed macro-level SRL processes when compared to participants in the declarative knowledge group.

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Quality education is important for the success of students in the United States and worldwide. The Federal Interagency Forum on Child and Family Statistics (2008) captured the significance of education in its publication, *America's Children in Brief: Key National Indicators of Well-Being,* by stating: "Education shapes the personal growth and life chances of children, as well as the economic and social progress of our nation" (p. 14). Educators agree that achieving a quality education requires that students focus on several diverse academic disciplines. Science is an important discipline in today's schools. This focus on science is necessary because science drives the world's economies. A 2007 U.S. government report entitled, *Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* stated: "the growth of economies throughout the world has been driven largely by the pursuit of scientific understanding, the application of engineering solutions, and continual technological innovation" (National Academy of Sciences, 2007, p. 41). The significance of scientific development to the world's economies makes science education important in the U.S. and worldwide. According to the U.S. Department of Education's Institute of Education Sciences, the number of high school graduates that have completed an advanced level science course rose from 35% in 1982 to 68% in 2004 (Planty, Provasnick, & Daniel, 2007). This growth points to an increased focus on the science curriculum in schools across the country.

Because of its significance, educators in the United States are concerned about the state of science education in this country. In order to assess the state of science education in the United States, the U.S. Department of Education's National Center for Education

Statistics publishes the National Assessment of Educational Progress (NAEP). According to the U.S. Department of Education, the NAEP "is the only nationally representative and continuing assessment of what America's students know and can do in various subject areas" (National Center for Education Statistics [NCES], n.d.). The NAEP report assesses students' performance at both the national and state levels within 11 distinct subject areas. The NAEP uses three main measures to evaluate students' performance in science topics. These three measures are conceptual understanding, scientific investigation, and practical reasoning. The highest grade-level assessed in the NAEP is the 12th grade. The NAEP's scoring range is zero to 300. In 1996, 2000, and 2005, the average scores for 12th graders on the science assessment never exceeded 150. These averages are concerning given the NAEP's minimum standard for basic understanding (146). These average scores fall far below the NAEP's guidelines for proficient (178) or advanced (210) understanding. There was no statistically significant difference between the overall science scores achieved by U.S. 12th graders in 2000 and the scores in 2005. However, scores in 2000 and the most recent data of 2005 both show a decrease in overall performance since 1996 (Grigg, Lauko, & Brockway, 2006). These lower scores in 2000 and 2005 mean a smaller percentage of students met the required threshold for proficient or basic understanding in 2005 than met the same threshold in 1996. Additionally, the U.S. Department of Education's *The Condition of Education in Brief* (Livingston, 2008) stated that students in the United States scored below the average score for science literacy achieved by students in 30 developed nations. This failure of U.S. students to excel in science when compared with students in other developed countries, coupled with falling scores on the NAEP's tests, leaves U.S. educators searching for new ways to improve science education.

The U.S. Department of Education's data discussed previously showed that more students are exposed to advanced scientific content in the classroom now than were exposed to it 20 years ago. However, the NAEP data on scientific performance indicated that in the period between 1996 and 2005 student performance decreased on the standardized science module. Therefore, students' increased exposure to science is having little effect upon the education system's goal of improving students' overall performance in the complex field of science. Students in the United States must improve their scientific knowledge to continue to be leaders in the pursuit of the scientific understanding that drives economic growth.

The Difficulties of Complex Systems

Understanding the core concepts of science topics is important for today's students and educators (Carey, 2000). In order to fully grasp these challenging topics, students must be able to understand and explain complex systems. Complex scientific systems such as the solar system, chemical interactions, or the circulatory system are often difficult to grasp because the components of the system are not physically available to students in the classroom (Azevedo, Guthrie, & Seibert, 2004). Thus, students must attempt to create an overall understanding of a complex topic by synthesizing a diverse set of representations of the component concepts. These representations could include text, videos, diagrams, and graphs (Azevedo, Guthrie et al., 2004).

As students' acquire knowledge about a particular subject, they store it as their mental model of that concept (Chi, 2005). Mental models are more than just definitions or surface facts and include a conceptual understanding of how the parts of the system operate together. Mental models facilitate students' ability to build on core knowledge and to infer other facts (Greene & Azevedo, 2008). An individual's mental model can be described using the subcomponents of knowledge: declarative, procedural, and self-regulatory knowledge (Schraw, 2006). Declarative knowledge includes specific labels, facts, definitions, and descriptions. The term procedural knowledge describes knowledge about how to use particular information to solve problems. The final term of the three, self-regulatory knowledge, describes an individual's knowledge about managing his or her personal learning (Schraw, 2006). Self-regulatory knowledge includes learners' beliefs about regulating their memory and thoughts as well as facts about what learning skills work best for them in certain domains.

Students combine these three types of knowledge to form a conceptual understanding. According to the science education literature, conceptual understanding is more than simply a large amount of declarative knowledge. Instead, to demonstrate a conceptual understanding of a science topic a student must be able to apply knowledge to real world problems (Roth, 1990). This application can include using existing knowledge to explain a phenomenon or as the basis for exploring a new phenomenon. Achieving conceptual understanding leads learners to ask clarifying questions that demonstrate an ability to utilize the knowledge.

Students that are just being introduced to a complex topic may successfully gain declarative knowledge about the topic, but often fail to reach a conceptual understanding (Greene & Azevedo, 2008). Science literacy requires that students have a mental model that includes both declarative knowledge and conceptual understanding. The creation and use of mental models is so important for understanding complex topics that "students have difficulty reflecting on complex phenomena without mental models" (Schraw, Crippen, & Hartley, 2006, p.125). Research suggests that new developments in the use of hypermedia based learning tools can help students reach a conceptual understanding of complex science topics (Scheiter & Gerjets, 2007).

Using Hypermedia as a Teaching Tool for Complex Topics

Developments in computer capabilities have allowed for the creation of hypermedia based tools. Hypermedia learning environments include multiple types of representations such as text, video, diagrams, and animation. These separate representations are interconnected to form a network (Scheiter & Gerjets, 2007). Jacobson and Archodidou (2000) cite several reasons why hypermedia environments improve students' ability to learn complex topics. First, hypermedia environments offer students the ability to gather and interact with information in a variety of ways. Additionally, hypermedia environments present information in a non-linear fashion allowing students to control when and how they view certain topics. For example, in a hypermedia environment, a student learning about a complex science topic, such as the solar system, has the option to read text, look at static diagrams or watch a video. The student chooses which of these tasks to do, which order to do them in, and whether or not to return to certain subjects. The high degree of interactivity in hypermedia environments allows students to construct knowledge in their own way while simultaneously increasing interest and motivation for a subject (Scheiter & Gerjets, 2007). After conducting their research, Jacobson and Archodidou (2000) asserted, "the use of an appropriately designed case and problem-centered hypermedia system may help students to construct qualitatively new understandings of complex scientific knowledge, and to retain this knowledge" (p. 179). However, research into the effectiveness of hypermedia as a tool for teaching complex topics has yielded mixed results. One possible reason for this is that not all the students using hypermedia tools possess the self-regulated learning (SRL) skills necessary to facilitate learning in the environments (Azevedo, 2005; Scheiter & Gerjets).

How SRL Supports Hypermedia

Recent research suggests that students using a hypermedia environment to learn complex science topics learn more and perform better on subsequent assessment when they effectively employ SRL processes (Azevedo, Guthrie et al., 2004; Greene & Azevedo, 2007; Jacobson & Archodidou, 2000; Schraw et al., 2006). Several models exist to describe the basic concepts of SRL. Each of these models has at its core the concept that students perform better when they regulate their own motivation, cognition, and behavior (Hofer, Yu, & Pintrich, 1998). Paul Pintrich (2000) defined SRL as “an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation and behavior, guided and constrained by their goals and the contextual features in the environment” (p. 453).

Self-regulated learning theory traces its origins to Albert Bandura’s social-cognitive theory (Schraw et al., 2006). Phillip Winne and Allyson Hadwin developed one of the most often used models of SRL. Winne and Hadwin describe SRL using four phases: perceiving the task, setting goals and planning, enacting tactics to approach goals, and adapting tactics (Winne & Hadwin, 1998). In phase one, task definition, the learner constructs a personalized understanding of the task using two parameters. The first parameter, task conditions, includes information about the task inferred from the outside environment. The second parameter, cognitive conditions, is information the learner retrieves from long-term memory (Winne, 2001). In the second phase, the learner establishes a goal to accomplish the task and sets forth a plan to reach that goal. In phase three, the learner applies strategies and tactics that were selected in phase two and adapts these strategies to ensure success. The fourth phase, adapting tactics, is optional and is performed when the learner feels that different tactics would have improved performance on the task. Results from the fourth phase alter the way a student approaches a similar problem in the future. Throughout each of these four phases, learners monitor their progress toward the completion of that phase and toward the overall learning goal. According to Winne and Hadwin (1998), “metacognitive monitoring is the key to self-regulating one’s learning” (p. 169). Monitoring progress towards a goal allows the learner to adjust the tactics and strategies being used during each phase, if necessary.

Research conducted using hypermedia as a tool to teach complex science topics has shown that the use of SRL processes improves learning (Azevedo, Winters, & Moos, 2004; Greene & Azevedo, 2007, 2008). Specifically, this research has shown that students who employ SRL processes while learning with hypermedia reach a conceptual understanding more often than students that do not effectively employ SRL processes. While certain SRL processes have been identified as aiding in the creation of a sophisticated mental model, more research is needed to determine if learners that reach a complex conceptual understanding use certain SRL processes more frequently than learners who gain declarative knowledge, but fail to reach a conceptual understanding.

Current Study

Researchers have studied SRL as it relates to hypermedia. Until recently, much of that research focused simply on changes in students’ declarative knowledge. New research into the use of SRL with hypermedia environments has begun to focus on the study of students’ mental models. This study of mental models allows researchers to learn more about students’ overall understanding of material. Better knowledge about how students learn difficult topics at the conceptual level will aid educators seeking to improve science education in the United States. Recent research conducted by Greene and Azevedo (2007) identified SRL processes associated with the acquisition of a sophisticated mental model of a complex science topic.

The research by Greene, Azevedo and others led me to ask a follow up question: Are there differences in the frequency with which students who reach an effective conceptual understanding of a topic utilize SRL processes as compared to students who gain only declarative knowledge about the topic, but do not reach a conceptual understanding? Previous research has studied differences between students that gain little to no knowledge and students that reach a conceptual understanding. However, researchers have not examined the differences between the latter group and students that gain only declarative knowledge.

After completing a task to learn about a complex science topic using hypermedia, students can be grouped according to posttest scores they receive. Some students gain neither declarative nor conceptual knowledge; these students are not the focus of this study. Other students gain declarative knowledge but fail to achieve conceptual understanding of the topic. A third group of students achieves conceptual understanding, which includes declarative knowledge. I wish to study whether there are distinct differences in the SRL processes employed by students classified into the last two groups. These differences in the use of SRL processes between the two groups may help researchers understand why some students fail to reach a conceptual understanding of a complex science topic. The differences in the SRL processes used by the two groups can be described by quantifying the SRL processes used. Students can be evaluated by how often they plan their learning, monitor the progress they are making towards their learning goals, use strategies, assess their motivation, and handle task difficulties (Greene & Azevedo, 2008; Pintrich, 2000; Winne, 2001; Zimmerman, 2001).

Research Questions

In this study, I will focus on five research questions:

Research Question 1: Are there differences in the frequency with which students use SRL planning processes between participants who only gain declarative knowledge from pretest to posttest versus participants who gain declarative knowledge and conceptual understanding?

Research Question 2: Are there differences in the frequency students use strategies between participants who only gain declarative knowledge from pretest to posttest versus participants who gain declarative knowledge and conceptual understanding?

Research Question 3: Are there differences in the frequency with which students monitor progress between participants who only gain declarative knowledge from pretest to posttest and participants who gain declarative knowledge and conceptual understanding?

Research Question 4: Are there differences in the frequency with which students handle task difficulty and demands between participants who only gain declarative knowledge from pretest to posttest and participants who gain declarative knowledge and conceptual understanding?

Research Question 5: Are there differences in the frequency students assess their interest for a topic between participants who only gain declarative knowledge from pretest to posttest and participants who gain declarative knowledge and conceptual understanding?

Literature Review

Science is an important discipline within the academic system in the United States. The U.S. Department of Education's 2005 *National Assessment of Educational Progress* stated, "the goal of school science is to engender conceptual understanding" (Grigg et al., 2006, p. 22). In this report, the Department of Education clarified that conceptual understanding requires that students must be able to use information to conduct scientific inquiry and reason practically in scientific endeavors. In concert with this statement, Schraw, Crippen, and Hartley (2006) stated that science instruction must help students construct conceptual knowledge.

Inherent in this requirement to reach a conceptual understanding of science is a need for students to understand the complex topics within science (Jacobson & Wilensky, 2006). Learning complex systems is frequently difficult for students (Jacobson, 2008). Some of the difficulty associated with learning complex systems is that the entire system is rarely available for direct study by the student (Azevedo, Guthrie et al., 2004; Kozma, Chin, Russell, & Marx, 2000). When properly used, hypermedia and other learning environments can help students gain conceptual understanding of complex science topics. Hypermedia assists students by allowing them to explore a complex topic using multiple representations in ways other learning environments cannot support. Additionally, students can use hypermedia environments at their own pace and can review troublesome items in a non-linear fashion. However, operating in a hypermedia environment does not guarantee that students will attain a conceptual understanding of complex science topics. It is possible that students will learn almost nothing or that they may gain solely surface level information and fail to gain a deeper understanding of the concepts (Azevedo et. al, 2005; Greene & Azevedo, 2008). Research suggests that certain self-regulated learning (SRL) processes are necessary for students to gain a conceptual understanding of science subjects when using hypermedia (Azevedo, 2005). A discussion of the factors that make learning a complex science topic difficult, as well as an understanding of how hypermedia environments can encourage learning of complex topics under the right conditions, is necessary when considering the factors that influence learning. Understanding differences in the use of self-regulated learning processes between students that gain only declarative knowledge and students that gain both declarative knowledge and a conceptual understanding will help researchers reach a better understanding of how students self-regulate their learning in hypermedia environments. This will allow researchers to help educators foster the conceptual understanding needed for science education.

Conceptual Understanding

Today there is a general agreement within the research community that conceptual understanding is comprised of at least three subcategories of knowledge (Schraw, 2006). Declarative knowledge is factual information about a particular topic. Procedural knowledge is information about how to utilize declarative knowledge. Finally, self-regulatory knowledge is knowledge about how to manage learning.

These three types of knowledge combine to form an individual's conceptual understanding of a topic. Conceptual understanding is more than just large amounts of declarative knowledge. Instead, in order to demonstrate conceptual understanding of a topic a student must successfully apply knowledge to explain real world problems (Roth, 1990.) The *National Science Education Standards* (National Research Council, 1996) define conceptual understanding in science as what a student knows, understands, and can do. The National

Assessment Governing Board (NAGB) published a new framework that will be used to conduct the NAEP's national science assessment in 2009. The focus of this framework is on conceptual understanding, which the NAGB defines as the "knowledge and use of science facts, concepts, principles, laws and theories" (NAGB, 2008, p. vii). For example, a student could demonstrate a conceptual understanding of the circulatory system by accurately describing the repercussions of a blockage of the flow of blood between the right ventricle and the lungs. The student may not have encountered this particular example before, but could draw upon declarative, procedural, and self-regulatory knowledge to describe this incident. In sum, science educators define conceptual understanding as knowledge that a student can apply and explain.

A mental model is a cognitive representation of an individual's conceptual understanding of a particular subject (Vosniadou, 1994). A mental model can be used to explain physical phenomena, and it can be manipulated mentally to solve problems (Chi, De Leeuw, Chiu, & Lavancher, 1994; Vosniadou & Brewer, 1994). For example, an individual's mental model of how an internal combustion engine works includes all the declarative, procedural, and self-regulatory knowledge that a person has about engines. Declarative knowledge includes information such as how many spark plugs are in an engine, and how much fuel it consumes at a certain speed. Procedural knowledge includes information about how the engine operates and how to solve a given problem with the engine. An individual's self-regulatory knowledge about engines includes information about effective ways to learn about engines. Students that fail to build useful and accurate mental models have a difficult time reflecting on complex topics and fail to reach a deep understanding of those topics (Schraw et al., 2006).

It is important for students to build accurate and useful mental models of complex science topics, but this is a difficult process (Greene & Azevedo, 2007). One reason that complex topics may be difficult for students to learn is that some key concepts within the topic may be counterintuitive (Jacobson & Wilensky, 2006). For example, students may have a difficult time understanding that the moon does not create its own light, rather the sun's light reflects off it. In the absence of formal teaching about a topic, students construct their own conceptual framework to explain phenomena that they observe (Hayes, Goodhew, Heit, & Gillan, 2003). These conceptual frameworks are difficult to correct and can be resistant to future revision (Carey, 2000). Vosniadou (1994) expressed this same concept when she described conceptual change in terms of shifts in mental models about a topic. Altering existing mental models is a difficult task. Carey (2000) advocated a shift in classroom cultures to allow students to build and construct their own knowledge to help combat problems with conceptual change and allow students to build accurate mental models. Research into conceptual understanding must account for both prior knowledge and the difficulties inherent in building a sophisticated understanding of a complex topic.

Another reason that complex topics can be difficult to understand is that they are inherently multilayered (Azevedo, 2005). Complex topics frequently contain intricate, nonlinear relationships that make them difficult for learners to grasp. Additionally, complex science topics are difficult for students to understand because frequently the systems are not available for students to view and manipulate (Azevedo, Guthrie et al., 2004). For example, as students attempt to learn about the influence of the moon on ocean tides it is not possible for students to view the entire tidal cycle and see the effects of the moon. Teachers, and their students, must try to construct an understanding of this complex topic from a set of representations that can include photos, videos, models, lecture, and other instructional techniques. Hypermedia learning environments can assist learners as they attempt to build more accurate mental models about complex topics.

Hypermedia and Conceptual Understanding

Improvements in electronic technologies allow for the development of a diverse and readily available set of interactive learning environments that are having a notable effect on learning in today's classrooms (Aleven, Stahl, Schworm, Fischer, & Wallace, 2003). The increase in the availability of electronic learning environments includes growth in the use of hypermedia as an instructional tool. Hypermedia tools are computer-based and consist of separate nodes of electronic information that are connected together using hyperlinks to form a network (Gerjets, Scheiter, & Schuh, 2008; Jacobson, 2008). The numerous unique teaching and learning characteristics of hypermedia tools have led many researchers and educators to predict that hypermedia learning environments would profoundly alter the way students learn complex science topics (Dillon & Gabbard, 1998).

Researchers have advocated for the use of hypermedia in teaching because it is "considered to improve comprehension by virtue of its capability of supporting structured access, rapid manipulation, and individual learner control" (Dillon & Gabbard, 1998, p. 326). Additionally, hypermedia environments are more engaging to learners than traditional learning environments, and hypermedia represents a more accurate form of representation of complex topics (Jonassen, 1989). Hypermedia environments allow authors to incorporate additional media that may fill gaps in the material presented by text alone. For example, a passage about a subject that students may not be familiar with, such as the solar system, can be supplemented with photos and drawings (Delany & Gilbert, 1991).When compared to traditional teaching methods, hypermedia environments allow students more flexibility to construct knowledge in their own way. Hypermedia environments allow users to exert a higher level of learner control than traditional teaching techniques such as textbooks or the classroom. Learner control allows students to manipulate multiple pieces of information, and alter the way they interact with this information. For example, learning environments that offer students learner control allow them to change their view, alter the sequence of material, select different content, and control the pace of their learning (Scheiter & Gerjets, 2007). Learner control allows learners to pursue information in the learning environment not only in a non-linear fashion but also at the pace that best fits their needs (Dillon & Gabbard, 1998). This freedom facilitates students' ability to construct knowledge into accurate mental models (Lawless & Brown, 1997). In sum, there are authors that advocate hypermedia as an instructional tool because it allows learners to access large quantities of information presented in unique ways over which the learner has a degree of control (Gerjets et al., 2008).

Problems with Hypermedia as a Teaching Tool

Despite the advantages advocated by some researchers, applications of hypermedia as a teaching tool have not produced all of the improvements in teaching and learning that have been predicted. Researchers have cited several reasons why using hypermedia as a teaching tool has not generated the results many thought it would. Two of the principle concerns about the use of hypermedia are disorientation and cognitive overload (Gerjets et al., 2008). Due to the non-linear nature of hypermedia tools, users can become disoriented as they move between nodes seeking information. This feeling of disorientation can detract from the learning experience by causing students to waste both time and cognitive resources trying to get reoriented.

Some authors have argued that the amount of learner control provided by hypermedia environments can be detrimental to the learning of students with low prior knowledge or limited experience operating a hypermedia environment. Dillon and Gabbard (1998) reviewed five quantitative learner control studies to determine if learner control had an effect on learning. They concluded that individual differences in both prior knowledge about a topic and experience with hypermedia environments can alter the effectiveness of learner control. Low prior knowledge about a topic influences the information students select, and the way they link that information to existing knowledge (Mitchell, Chen, & Macredie, 2005). Students with low prior knowledge about a topic are less likely to navigate the environment efficiently. These learners tend to move more haphazardly across the subject matter without exploring it in-depth. Learners with low prior knowledge are also more likely to experience disorientation within the environment because they are less able to remember where they have been or where to find the information they seek (Mitchell et. al., 2005). Students can also exhibit low ability to operate the hypermedia environment. This ability influences students' navigation techniques in several ways. Experienced users are able to navigate through more pages faster than inexperienced users. Experienced users are also more likely to take a non-linear path through the information. Inexperienced users typically follow a linear path reducing one of the key strengths of hypermedia learning environments. Students with low prior knowledge or little experience operating in a hypermedia environment frequently were unable to capitalize on the advantages that learner control affords in hypermedia learning environments.

Cognitive overload also detracts from the learning experience by reducing a student's ability to focus on the material. Cognitive load represents the tax that conducting a task puts on an individual's cognitive resources (Niederhauser, Reynolds, Salmen, & Skolmoski, 2000). Working memory is the system that handles the temporary storage and processing of new information (Baddeley, 2001). In this capacity, it draws on knowledge already stored in long-term memory (LTM) and processes the new information presented in a learning environment. There are limits to the number of items that can be processed in working memory at any one time. Exceeding these limits can cause cognitive overload. Users learning in a hypermedia environment must navigate the environment while simultaneously planning what content areas to investigate, how to manage time, and what goals are important (Greene & Azevedo, 2007). Learning in a hypermedia environment requires that students simultaneously integrate new information into their existing knowledge and monitor their understanding to aid them in selecting future content (Niederhauser, et. al., 2000). The constant processing required when learning in a hypermedia environment places increased demands on learners' working memory. The additional requirements created by the increased learner control in a hypermedia environment can be germane cognitive load (van Merriënboer & Sweller, 2005). Germane cognitive load is relevant additional load over and above the cognitive load required to learn a new task. Ordinarily, germane cognitive load contributes to the creation of conceptual knowledge; however, when coupled with the existing cognitive load created by learning a complex topic, it can detract from the overall learning experience. Research suggests that the use of self-regulated learning processes can mitigate some of the effects of disorientation and cognitive overload and improve the outcome of students' learning in hypermedia (Azevedo, 2005).

Self-Regulated Learning

Self-regulated learning is important for successful learning and academic achievement (Boekaerts & Cascallar, 2006). Students with better self-regulated learning skills typically outperform students with weak self-regulated learning skills in academic settings (Schraw et al., 2006). Self-regulated learning refers to the processes students use to actively manage their learning by setting goals, selecting strategies to reach those goals, implementing these strategies, monitoring their progress, and adapting the strategies to meet the goals (Winne, 2001). This process includes the monitoring, regulation, and control of behavior, motivation, and cognition (Pintrich, 2000). There are several different definitions of self-regulated learning. However, there are core concepts that are central to most SRL theories. The self-regulated student actively constructs meanings, goals, and strategies from both external and internal sources of information (Pintrich, 2000). SRL theories generally involve a feedback loop whereby learners monitor their effectiveness at a given task and alter their actions to improve performance (Zimmerman, 2001). In addition, SRL processes act as a mediator between the person, the environment, and actual achievement (Pintrich, 2000).

The development of self-regulated learning theory began in the 1970s after several changes in the educational focus of schools in the United States. Following World War II, there was a focus in schools on the mental ability of students. Educators classified students by mental ability, and advised teachers to teach material in ways that maximized an individual student's ability. Beginning in the 1960s, educators altered their views and began to factor in students' history and socio-economic status when determining the best ways to educate. As part of this movement, educators recommended changes that reduced the reliance on grades for promotion and increased concerns about students' social adjustment

(Zimmerman, 2001). In the 1970s, there was a backlash to this movement and a push across the country for improved standards of education for teaching, curriculum requirements, and achievement. All three shifts in educational focus had at their core the same fundamental assumption that students were generally reactive to their environments (Zimmerman, 2001). Self-regulated learning theory was developed based on a belief among theorists and researchers that students can and do improve their own learning proactively.

Self-regulated learning theory began with Albert Bandura's work on Social Cognitive Theory (Dinsmore, Alexander, & Loughlin, 2008). In Bandura's learning theory, he outlined his concept of reciprocal determinism, which was his addition to the prominent theory at the time, behaviorism. Reciprocal determinism described the interaction between the person, the person's environment, and the person's behavior (Bandura, 1986). Specifically, Bandura noted that while the environment influences a person's behavior, the individual's behavior also influences the environment (Miller, 1993). Bandura's theories led to the development of SRL as a field of study in the 1980s. Self-regulated learning became increasingly important in educational research in the 1990s (Dinsmore et al., 2008). Self-regulated learning is generally discussed in terms of its use in academic domains. The focus of SRL researchers on a proactive view of learning sets SRL theory apart from the theories that dominated learning in the past (Zimmerman, 2001).

The Winne and Hadwin model of self-regulated learning consists of four phases: perceiving the task, setting goals and planning, enacting tactics to approach goals, and adapting tactics (Winne & Hadwin, 1998). During the first phase, perceiving the task, the learner uses two primary parameters to construct a definition of the task. The first parameter, task conditions, includes information about the task inferred from the outside environment.

This includes material from the written instructions for a task, from fellow classmates that ask questions, and from the course textbook. The second parameter, cognitive conditions, is information the learner retrieves from long-term memory (Winne, 2001). For example, cognitive conditions include facts the student has stored about similar assignments in the past, such as the emotions generated by a similar type of assignment. In the next phase, setting goals and planning, the learner creates a goal and a plan to reach that goal. The learner's previous experiences influence both the goal and the plan. The third phase of the process begins when the learner starts to apply the strategies and tactics selected in the second phase. This phase is where the actual task is accomplished. The fourth phase is optional and is performed only if the learner notes that significant changes need to be made to the processes that will be used to solve similar problems in the future.

Throughout each of the four phases of Winne and Hadwin's (1998) model of SRL, learners monitor their progress toward the completion of that phase and toward the overall learning goal. Self-regulated learning is not a purely linear process; instead, it is recursive in nature. A student monitoring progress in the second phase, setting goals and planning, may determine that more planning is needed before moving into phase three. This monitoring decision can cause the student to repeat phase two. Additionally, the student may make a decision in phase three that current strategies are not going to lead to successful completion of the task. This decision requires the student to reassess the overall task again by repeating phase one.

Roger Azevedo and his colleagues have developed a model of SRL specifically designed to allow researchers to apply self-regulated learning theory to learning complex topics with hypermedia. This model is based on the SRL theories described above but expands upon them by identifying both macro and micro-level SRL processes. In their work (Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie et al., 2004; Azevedo, 2005; Greene & Azevedo, 2008) they have outlined 31 micro-level SRL processes that can be used to describe the actions and thoughts of learners working in a hypermedia environment. These micro-level processes include tangible actions such as taking notes, cognitive decisions about whether or not the individual has learned a particular subject, and goal setting. These micro-level processes are grouped into five macro-level categories that align with the processes described by the models of Winne and Hadwin, Pintrich, and Zimmerman. These five groups are planning, monitoring, strategy use, interest, and handling of task difficulty and demands (Greene & Azevedo, 2008). Thus, micro-level SRL processes are the specific activities that learners engage in when they regulate their learning at a macro-level. (See Appendix A for a list of all the micro and macro-level SRL processes).

Previous studies using Azevedo and colleagues' model have examined links between these micro-level SRL processes and several different aspects of learning. These studies have focused on a diverse range of topics including the use of scaffolding, differences between gifted and grade-level students, and differences in learning outcomes (Azevedo, 2005; Azevedo, Cromley, Winters, Moos, & Greene, 2005; Greene, Moos, Azevedo, & Winters, 2008). The learning outcomes research is most pertinent to this study.

Azevedo and colleagues (Azevedo, Guthrie et al., 2004) explored the hypothesis that training college students on SRL would improve their ability to learn a complex topic using hypermedia. In this study, Azevedo divided students into a control group and an experimental group. The control group was tasked to learn as much as they could about the circulatory system in 45 minutes using a hypermedia environment. Students in the experimental group received 30 minutes of training on SRL and were given the opportunity to practice regulating their own learning on a practice test. After completing the practice test, the experimental group received the same amount of time to complete the same task in the hypermedia environment. The researchers concluded that more students in the experimental group reached a conceptual understanding of the circulatory system than students that did not receive the training, and attributed this difference to differences in the use of SRL processes.

When learning about complex science topics, students often gain declarative knowledge but fail to reach a conceptual understanding (Azevedo, 2005). The Azevedo and colleagues model was used in two studies to show that students who effectively regulated their learning while working in a hypermedia environment were better able to obtain a conceptual understanding (Azevedo, Guthrie et al., 2004; Greene & Azevedo, 2007). Both of these studies explored the differences in the use of micro-level SRL processes between students that improved their conceptual understanding and students that failed to improve their conceptual understanding. For example, Azevedo, Guthrie, et al. (2004) found that learners that gained a conceptual understanding of a complex topic used three micro-level SRL processes, create sub-goals, activate prior knowledge, and plan, more frequently than learners that did not reach a conceptual understanding. Greene and Azevedo (2007) found four different micro-level SRL processes that students that reached a conceptual understanding used more frequently than students that failed to reach a conceptual understanding. These micro-level processes were inference, coordinating information sources, expectation of adequacy of content, and feeling of knowing. However, researchers in both of these studies did not account for changes in declarative knowledge among participants. In the current study, I focus only on students who demonstrated improved declarative knowledge. This study focused on these students because past researchers have studied self-regulated learning and conceptual understanding of complex science topics including students' changes in both conceptual understanding and declarative knowledge. However, researchers have not specifically compared those who gained both declarative and conceptual knowledge with those who only gained declarative knowledge (Azevedo et al., 2005).

Measuring SRL

Two key methodological issues must be resolved to effectively measure SRL processes. First, what is the best way to capture the SRL processes learners are performing? Previous studies have used both self-report procedures and think-aloud procedures. The second question that must be resolved is whether to use micro-level or macro-level processes to describe students' self-regulatory actions. Using the Azevedo and colleagues model, it is possible to determine how often learners perform each of 31 micro-level SRL processes. It is also possible to combine these values to get a frequency for the use of the five macro-level processes.

Previous researchers have examined the effect macro-level SRL processes have on learning, however much of that research was focused on self-report data (Greene & Azevedo, 2008). For example, Bembenutty (2007), used the Motivational Strategies for Learning Questionnaire (MSLQ; Duncan & McKeachie, 2005), a self-report measure, to assess students' use of learning strategies and course-specific motivation. Dinsmore and colleagues (2008) and Winne and Jamieson-Noel (2002) noted that self-report data are notoriously unreliable. Research has shown that students do not accurately report the SRL processes they use during a learning event (Winne & Jamieson-Noel, 2002). In general, students often fail to recall their activities or report them inaccurately. In contrast to self-report measures, Azevedo and colleagues have used a think-aloud protocol to capture students' SRL processes (Ericsson & Simon, 1993). Researchers using a think-aloud protocol request that participants verbalize all their thoughts and actions. Ericsson and Simon's research demonstrated that the use of think-aloud protocol to capture what participants are thinking does not alter the participants' thoughts (Ericsson & Simon, 1998). The crucial step to ensuring that using a think-aloud protocol does not alter participants' thoughts is to ask participants to verbalize but not describe or explain their actions. The think-aloud protocol has advantages over self-report because students' actions are captured and recorded by trained observers instead of relying on students' recall of events (Zimmerman, 2008). Zimmerman (2008) stated that "clearly the think-aloud methodology is an effective way to assess students' self-regulatory processes" (p. 173).

Researchers in two previously mentioned studies (Azevedo, Guthrie et al., 2004; Greene & Azevedo, 2007) focused specifically on micro-level SRL processes. There is value in understanding which micro-level processes lead to success; however, there is also value in exploring the differences that appear when using macro-level SRL processes to distinguish the performance of two groups of students. SRL is a very individualized process (Pintrich, 2000). Each person employs self-regulatory processes in a unique way. It is plausible that studying SRL only at the micro-level misses key trends in how students actually regulate their learning. For example, two students given the same learning task may both improve their understanding of a topic from almost nothing to a complex and deep understanding with a robust and accurate mental model of the topic. One student may do this by drawing, but not taking notes, while the other might take notes on the topic but not draw. Drawing and taking notes are different micro-level SRL processes, but they are both classified as the same macro-level process, strategy use. Focusing strictly on the micro-level SRL processes (e.g., draw or take notes) may blind researchers to the predictive nature of the macro-level SRL process (e.g., strategy use.) In this example, the two participants' opposite use of micro-level processes would essentially cancel out the effect of each process in the analysis. It is possible that the use of strategies in general is more predictive of students' success than the use of any specific strategy (Greene & Azevedo, 2008). More research is needed regarding the predictive utility of macro-level SRL processes.

Research Questions

Reaching a conceptual understanding of complex science topics is important for today's students. However, building an accurate and complete mental model of these complex topics is difficult. Hypermedia tools are being used in classrooms to enhance students' learning. There is evidence that improved self-regulated learning processes can enhance learning using hypermedia. Previous researchers have studied the relationship between the use of SRL processes and enhanced conceptual understanding. However, none of these researchers has used a group design that separates students that gain only declarative knowledge from students that reach a conceptual understanding. Only participants that gained declarative knowledge about the circulatory system during the learning period were included in this study. Prior research has focused on which SRL processes predict gains in students' conceptual understanding, but little is known about the differences between students that gain only declarative knowledge and students that reach a conceptual understanding. Knowledge about the differences in the frequency with which students in each of these two groups employ SRL processes would assist educators and software developers as they work to improve students' learning of complex topics with hypermedia (Azevedo et. al, 2005). In this study, I used a think-aloud protocol to assess differences in the macro-level SRL processes used by students learning about a complex science topic, the circulatory system, to answer these five research questions:

Research Question 1: Are there differences in the frequency with which students use SRL planning processes between participants who only gain declarative knowledge from pretest to posttest versus participants who gain declarative knowledge and conceptual understanding?

Research Question 2: Are there differences in the frequency students use effective strategies between participants who only gain declarative knowledge from pretest to posttest versus participants who gain declarative knowledge and conceptual understanding?

Research Question 3: Are there differences in the frequency with which students monitor progress between participants who only gain declarative knowledge from pretest to posttest and participants who gain declarative knowledge and conceptual understanding?

Research Question 4: Are there differences in the frequency with which students handle task difficulty and demands between participants who only gain declarative knowledge from pretest to posttest and participants who gain declarative knowledge and conceptual understanding?

Research Question 5: Are there differences in the frequency students assess their interest for a topic between participants who only gain declarative knowledge from pretest to posttest and participants who gain declarative knowledge and conceptual understanding?

Method

Participants

For this study, I conducted a secondary analysis of data collected for an ongoing study (Greene, Costa, Robertson, Yi, & Deekens, accepted for presentation). During the 2007-2008 school year at a large public University in the Southeast, 170 undergraduate students participated in this study. Participants were recruited in their education classes. The participants consisted of 103 females and 67 males (mean age 19.9 years, SD=2.14 years). In exchange for their participation, students received extra credit in the course in which they were recruited. Only one potential participant elected not to participate after reviewing the procedures. No data are available for this individual. Pretest scores indicated that in general these participants did not have much knowledge about the circulatory system.

Measures

Materials for this study consisted of a consent form, demographic questionnaire, and a paper and pencil pretest and posttest. All participants completed the demographic questionnaire that included basic information such as gender, age, academic major, and grade point average. The questionnaire also contained a section where participants stated experience they had with health and biology, including coursework and work experience.

Researchers used the pretest and posttest to measure participants' declarative and conceptual knowledge about the circulatory system. These tests were the same as measures used successfully in previous studies (Azevedo, 2005; Azevedo, Guthrie et al., 2004). See

Appendix B for a blank pretest. The pretest and posttest were exactly the same, although participants were not told this. Both tests consisted of three distinct sections. The first section participants encountered was the matching section where participants attempted to identify the definitions of 13 terms by matching the term with the appropriate definition. This section measured participants' declarative knowledge about the circulatory system. On the second section of the test, labeling, participants were asked to label 14 components of the human heart. The results of the labeling section were not used in this study. The final section of the tests consisted of an open-ended essay prompt that asked participants to "Please write down 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." Researchers designed this essay to measure participants' conceptual understanding of the circulatory system. Previous researchers have reviewed the reliability and validity of scores from both the pretest and posttest (Azevedo, Moos, & Greene, 2007). Reliability estimates were computed for the full 171-participant sample. Pretest reliability, across all three measures, was 0.78 and posttest reliability was 0.82. Azevedo and colleagues (2007) used factor analysis to confirm support for the construct validity of these measures.

Hypermedia Learning Environment (HLE)

The participants in this study used a commercially available hypermedia-learning environment called Microsoft Encarta (2007). Researchers selected the three articles from Encarta deemed most useful for learning about the circulatory system. These three articles, the heart, blood, and circulatory system, consisted of 41,380 words divided into 18 sections, with 256 hyperlinks, 40 illustrations and one video. Each of the three primary articles had a hyperlinked outline allowing learners to link to particular topics. The articles also contained hyperlinks to the video and photos. Participants were not limited to the three articles; they could access anything in Encarta, but they were asked not to access the internet or use Encarta's dictionary function.

Procedure

The procedure for this study was similar to the one used by Azevedo and colleagues in previous studies (Azevedo, Guthrie et al., 2004). Sessions were conducted by appointment and with only one participant and one researcher present. Participants were welcomed to the lab and informed that the entire study would take approximately 90 minutes. The researcher told participants they could leave the experiment at any time without penalty and participants were asked to sign in to receive their extra credit. Once they agreed to participate, participants read and signed the consent form. The researcher was available to answer any questions about the consent form. After completing the consent form, participants were given as much time as they needed to complete the demographic questionnaire.

Next, the researcher gave participants instructions on how to complete the pretest. Participants did not have access to any instructional materials before or during the pretest. Participants were given a maximum of 20 minutes to complete the pretest, however, they were asked to inform the researcher if they finished early. The researcher introduced participants to each section of the test one page at a time, and read aloud the essay prompt. Additionally, the researcher instructed participants to complete the test sections in order, from matching to labeling to the essay, without flipping back and forth between the sections. The researcher remained in the room to answer any questions not related to the content of the test. When participants finished the pretest, the researcher conducted a tour of the hypermedia-learning environment.

The tour introduced participants to the three primary articles, heart, blood, and circulatory system, while simultaneously introducing the participant to the controls of Encarta. The orientation to the controls included instruction on how to access and control the heart video, how to utilize Encarta's search functions, and how to navigate within Encarta using the forward and back buttons. The researcher also showed participants how to use highlighted hyperlinks within articles to get more information on a topic or to move between articles. While small variations in the tour between researchers were possible, researchers were trained to follow a script designed to standardize all research procedures.

After the researcher answered any questions the participants had about the hypermedia environment, the participants were introduced to the think-aloud process. The researcher told the participants that they should verbalize everything they were thinking. This included reading aloud, stating any actions they were taking in the hypermedia environment (e.g., clicking on the heart article), and stating when they took notes. To solidify their understanding of the think-aloud process, participants practiced thinking-aloud using an Encarta article unrelated to the learning task. The researcher directed participants to an Encarta article on Michael Jordan and asked them to think-aloud for one to two minutes. The researcher answered any questions participants had about the think-aloud process or Encarta navigation.

After completion of the tour and the think-aloud practice session, the researcher introduced participants to the learning task. The researcher read the learning task aloud to participants and posted a written copy of the learning task where the participants could see it throughout the experiment. The learning task stated:

> You are being presented with a hypermedia encyclopedia, which contains textual information, static diagrams, and a digitized video clip of the circulatory system. We are trying to learn more about how participants use hypermedia environments to learn about the circulatory system. Your task is to learn all you can about the circulatory system in 30 minutes. Make sure you learn about the different parts and their purpose, how they work both individually and together, and how they support the human body. We ask you to 'think aloud' continuously while you use the hypermedia environment to learn about the circulatory system. I'll be here in case anything goes wrong with the computer or equipment. Please remember that it is very important to say everything that you are thinking while you are working on this task.

Participants were given 30 minutes to learn as much as they could about the circulatory system. Participants were allowed to take notes. The researcher remained in the room to answer any procedural questions, help with the technology, and provide time prompts at 20 minutes, 10 minutes and two minutes remaining. During this 30-minute period, participants were both audio and video taped. The audio tape captured the think-aloud process, while the video camera was utilized to capture what the participants were doing in the hypermedia environment and when they took notes. The video camera captured only the screen, desk area, and the side of participants' head. The video camera did not show participants' faces, but was positioned to allow researchers to determine where participants were looking while conducting the learning task. At the completion of the 30 minutes, all recording was stopped, the hypermedia environment was closed, and any notes that were taken were removed from the participant's work area and placed in the participant's file.

Finally, participants were given the posttest. Participants were informed that they could take up to 20 minutes to complete the posttest, but that they could stop whenever they were finished. The posttest was the same as the pretest, and participants were again asked to move through the test in the order it was presented without flipping back and forth between sections. Participants did not have access to any notes or to the hypermedia environment during the posttest. When the participants completed the posttest their elapsed time for the posttest was recorded, and they were asked not to discuss the experiment with any of their classmates.

Scoring

Scoring and coding of the transcripts was done based on the method developed by Azevedo and colleagues and used in previous studies (Azevedo, 2005). Trained graduate students graded each pretest and posttest on each of the three sections: matching, labeling, and the mental-model essay.

Graduate students graded the first section, matching, by assigning participants one point for a correct answer and zero points for a wrong answer. Possible scores on this section ranged from zero to 13. Scores on the matching section of both pretest and posttest were tabulated for further analysis. The labeling section was scored in a similar way with one point awarded for a correct answer and zero points for a wrong answer. The possible range of scores for this section was zero to 14. Scores on the labeling section were not used for this study.

Two graduate students scored the mental-model essay portion of each test individually. A scoring rubric was used that has been applied in previous studies (Azevedo, 2005; Azevedo, Cromley, et al., 2004). The scoring rubric was originally developed with the help of a nurse practitioner familiar with the subject matter (Azevedo, Cromley, et al., 2004). The primary goal of the analysis of the essays was to note qualitative shifts in participants' mental models from pretest to posttest. The Azevedo and colleagues mental model scheme consists of 12 separate mental models that represent various levels of understanding from zero understanding to an accurate and complete understanding. The 12 mental models are: 1) no understanding, 2) basic global concept, 3) basic global concept with purpose, 4) basic single loop model, 5) single loop with purpose, 6) advanced single loop model, 7) single loop model with lungs, 8) advanced single loop model with lungs 9) double loop concept, 10) basic double loop model, 11) detailed double loop model, 12) advanced double loop model (Azevedo, 2005). See Appendix C for a complete view of the mental model scheme.

Each value on this mental model scale represents a different degree of conceptual understanding of the circulatory system. However, there are three qualitatively different levels of understanding within the 12 scores (Greene & Azevedo, 2008). Models one through six represent slightly different mental models of the circulatory system. Models one, two, and three are the lowest levels of understanding. Models four, five, and six are single loop models. Students that have a mental model between four and six recognize that blood circulates, but fail to note the significance of the lungs to the circulatory system. The first qualitative difference in an individual's mental model comes between models six and seven. Specifically, researchers assign a mental model of seven or higher when a participant's essay demonstrates that the lungs are a part of the circulatory system. The second qualitative difference in mental models occurs between models eight and nine with the recognition that blood flows in a double loop instead of a single loop around the body. The broader mental model categories are “low” (models 1-6), “intermediate” (models 7-8), and “high” (models 9-12). The use of the broader mental model categories captures participants’ qualitative shifts in mental models.

Two trained graduate students reviewed the essay portion of each participant’s pretest and posttest and assigned the proper numerical value to each essay according to the mental model scheme. Essays received a score from one to 12. For example, a participant who stated that the heart is the circulatory system’s pump, blood circulates, and the purpose of the circulatory system is to transport oxygen and nutrients, but failed to mention that it is a double loop that includes the lungs would receive a score of five. Inter-rater agreement for this process was 99.4% (agreement on 334/336 essays). The primary investigator, a faculty member, scored the two essays where there was a disagreement and this score was used.

Transcribing and Coding

In order to capture the SRL processes performed by participants, graduate and undergraduate lab members transcribed the participants’ audio tapes. All spoken words were transcribed including words that were read directly from the hypermedia environment. If words were difficult to understand on the audio tape, transcribers could attempt to verify them using the video, although this was not always successful. Due to a computer failure, video for 11 participants was lost. These participants were excluded from the remainder of the study, leaving the study with 159 participants. Each participant’s transcript was a separate Microsoft Word document.

After a transcript was completed, it was coded. Coding is the process of labeling each of the participants' verbalizations as either one of the SRL micro-level codes or labeling the segment as not codable. See Appendix D for a sample coded transcript. Before graduate students began coding transcripts, they received individual training from the primary investigator. Graduate students in training conducted coding on sample transcripts and met with the primary investigator to ensure competence. Only after completing training did graduate students begin coding transcripts from this study.

The primary researcher and a team of trained graduate students coded every transcript by labeling each segment with the appropriate micro-level SRL processes or labeling the segment as not codable. Words read directly from the hypermedia environment were not coded. Micro-level codes can be grouped into five macro-level processes. The self-regulatory processes are: (a) the macro-level process planning which includes micro-level processes planning, setting subgoals, and recycling goals in working memory; (b) the macro-level process monitoring which includes the micro-level processes expectation of adequacy of content (plus and minus), task difficulty, judgment of learning (plus and minus), feeling of knowing (plus and minus), content evaluation (plus and minus), monitor progress towards goal, time monitoring, and monitor use of strategies; (c) the macro-level process strategy use which includes the micro-level processes coordinating information sources, read notes, memorize, prior knowledge activation, summarize, take notes, draw, re-read, control video, search, inference, select a new information source, and knowledge elaboration; (d) the macro-level process task difficulty and demands which includes only one micro-level process: help seeking behavior; (e) the macro-level process interest which includes the micro-level processes, interest (plus and minus). Further details on the coding scheme are provided in Appendix A.

The first coder reviewed the transcript and the video, physically labeling each segment on the transcript with one of the micro-level SRL processes. The video was predominantly used to verify the transcript and to view items not recorded on the audio tape (e.g., participant takes notes). A second coder reviewed the transcript and video and noted any segments that he or she believed were miscoded. Differences were resolved through discussion between the two coders.

Data Preparation

Participants were divided into two groups for analysis. The first group consisted of participants that improved their declarative knowledge from pretest to posttest, but failed to reach a conceptual understanding. This group consisted of participants that improved their matching score by four or more, but failed to reach a high mental model of the circulatory system. These participants were placed into the “declarative knowledge” group (26 participants). Thus, the “declarative knowledge” group contained participants with mental model scores on the posttest that were classified as “low” or intermediate” (values of eight or less). The second group consisted of students that improved their declarative knowledge (improvement of four or more on matching) and did reach a high conceptual understanding on the posttest. Participants that improved their mental model to “high” (score of 9 or higher) were placed into the “conceptual understanding” group (36 participants). Participants that failed to make an improvement of at least four on the matching section (declarative knowledge) from pretest to posttest were excluded from this study. The intent of this study was to focus only on students that showed some improvement in their knowledge of the circulatory system. The required change of four was selected after reviewing participants' scores to ensure that enough participants reached the criteria. Of the 159 participants, 62 had an improvement of at least four on the matching section of the tests. No participants had lower mental model scores on the posttest essay than on the pretest essay. To satisfy my interest in macro-level SRL codes, the micro-level codes were summed for each participant to generate a single value representing the number of times each participant performed one of the five macro-level processes. For example, a participant's total value for the macro-level process interest was calculated by adding the number of interest-plus and interest-minus codes recorded for that participant.

Data Analysis

These two groups were compared using the macro-level codes of planning, monitoring, strategy use, task difficulty and demands, and interest. I used a combination of t-tests, chi-squared tests, and Mann-Whitney U tests to see if there were statistically significant differences in the number of times participants in the "conceptual understanding" group performed the five macro-level processes when compared to the number of times members of the "declarative knowledge" group performed the macro-level processes. To control for Type I errors, I employed the Holm's Sequential Bonferroni adjustment technique to evaluate the p-values generated by these tests (Hancock & Klockars, 1996). This analysis was done to determine if there were differences between students that reach a conceptual understanding and students that gained only declarative knowledge in terms of the frequency that participants in each group employ self-regulated learning processes.

Results

This study addressed five research questions. The hypotheses for the study were that there would be differences in the frequency with which students in the two groups performed each of the five macro-level SRL processes. This section describes the analyses conducted to answer each of the research questions. Prior to the discussion of the questions, descriptive statistics are presented along with correlations.

Descriptive Statistics

Table 1
Descriptive statistics are shown for each variable.

Measure	Mean		Standard deviation		Skewness		Kurtosis		Median	
	DK	CU	DK	CU	DK (se)	CU (se)	DK (se)	CU (se)	DK	CU
Matching Pretest	4.85	6.67	2.34	2.27	-0.39 (0.46)	-0.74 (0.39)	-0.91 (0.89)	-0.82 (0.77)	5.00	7.00
Matching posttest	10.62	12.33	2.25	1.57	-0.97 (0.46)	-2.38 (0.39)	0.44 (0.89)	4.70 (0.77)	11.00	13.00
Mental model pretest	4.12	6.08	2.07	1.83	0.07 (0.46)	-1.35 (0.39)	-1.06 (0.89)	1.11 (0.77)	4.00	7.00
Mental model posttest	6.88	11.08	1.97	1.29	-2.26 (0.46)	-0.91 (0.39)	4.90 (0.88)	-1.03 (0.77)	8.00	12.00
Planning	4.69	6.17	4.13	5.10	1.05 (0.32)	0.869 (0.39)	0.319 (0.88)	-0.431 (0.77)	3.5	5
Monitor	16.27	19.7	12.3	14.2	0.949 (0.46)	0.626 (0.39)	0.154 (0.88)	-0.854 (0.77)	13	16
Strategy Use	83.5	89.2	26.6	24.0	0.262 (0.46)	-0.142 (0.39)	-0.318 (0.88)	-0.642 (0.77)	80.5	91.5
Strategy No SNIS	48.8	55.8	26.9	24.1	0.62 (0.46)	0.153 (0.39)	0.125 (0.88)	-0.502 (0.77)	45	55.5
Task Difficulty	0.039	0.05	0.19	0.23	5.1 (0.46)	4.05 (0.39)	26 (0.88)	15.2 (0.77)	0	0
Interest	0.46	2.28	3.69	3.39	-0.926 (0.46)	1.96 (0.39)	5.42 (0.88)	3.9 (0.77)	0	1

DK = Declarative knowledge group; CU= Conceptual understanding group

Correlations

The descriptive statistics table above shows that not all the variables used in this study were normally distributed. To account for this, several variables were treated as either ordinal or dichotomous. In order to compute appropriate statistics for the correlation matrix, each variable was classified by type as shown in the table below.

Table 2

Variable Type

Variable	Label	Type
Matching pretest:	Score on matching pretest	continuous
Matching posttest:	Score on matching posttest	continuous
Mental Model pretest:	Pretest mental model	ordinal
Mental Model posttest:	Posttest mental model	ordinal
MMGroup H vs. Not:	Grouping variable (DK vs. CU)	dichotomous
Macroplan:	Planning	ordinal
Macromonit:	Monitoring	ordinal
MacroSU:	Strategy use	continuous
SUnoSnis:	Strategy use without SNIS	continuous
MacroTD:	Task difficulty and demands	dichotomous
INTPlsubMin:	Interest	ordinal

Next, the appropriate statistic was computed for each correlation. For example, when calculating the correlation between two continuous variables a Pearson’s r correlation was used. When calculating the correlation between two ordinal variables a Spearman’s rho correlation was calculated. The results of the correlations are shown in the correlation matrix on the next page.

Table 3
Correlation matrix

	Matching pretest	Mental model pretest	Matching Posttest	Mental Model posttest	Group	Planning	Monitoring	Strategy Use	Strategy use no SNIS	Task difficulty
Mental model pretest	0.426**									
Matching posttest	0.692**	0.280*								
Mental Model posttest	0.340**	0.440**	0.469**							
Group	-0.369**	-0.469**	-0.417**	-0.884**						
Planning	-0.057	0.077	0.027	0.153	-0.149					
Monitoring	0.142	0.139	0.112	0.117	-0.109	0.555**				
Strategy Use	0.019	0.146	0.054	0.041	-0.113	0.500**	0.549**			
Strategy use no SNIS	-0.054	0.061	0.017	0.111	-0.138	0.396**	0.539*	0.809**		
Task Difficulty	-0.084	-0.046	-0.216	0.061	-0.39	-0.061	-0.002	0.152	0.097	
Interest	0.106	0.131	0.104	0.303*	-0.255*	-0.122	-0.018	0.107	0.149	0.075

Note: ** Correlation is statistically significant at the 0.01 level; *-Correlation is statistically significant at the 0.05 level.

The Sample and Prior Knowledge

The sample for this project was selected from an original sample of 159 participants. Participants chosen for this project had an increase from pretest to posttest of at least four on the declarative knowledge measure. Thus, participants that scored a 10 or higher out of a possible 13 on the pretest could not be included regardless of performance. Of the 159 participants in the larger sample, 50 (31%) had an initial score on the matching pretest that was 10 or higher.

Of the 62 participants in the sample for this project, 26 were placed in the declarative knowledge group and 36 were placed in the conceptual understanding group. Within the conceptual understanding group, all participants scored at least a seven on the posttest matching measure. Twenty-nine of the 36 (81%) participants in the conceptual understanding group scored the maximum 13 on the posttest matching section. By comparison, of the 26 participants in the declarative knowledge group only 7 (27%) scored the maximum score of 13 on the matching posttest. Similarly, within the larger sample of 159 participants, 88 participants demonstrated a conceptual understanding by scoring a nine or higher on the posttest mental model measure. Of these 88 participants, no one scored lower than six on the matching measure. This demonstrated that participants that scored high on the posttest conceptual understanding measure also demonstrated declarative knowledge on the posttest.

To determine the effect that prior knowledge had on performance several calculations were made using the number of biology courses students reported they had taken. Students self-reported the number of biology courses they had taken in both high school and college on the demographic questionnaire. Biology coursework was chosen as a measure of prior knowledge because of its relationship to the subject matter of this project. Of the 159 participants in the larger sample, 110 scored less than 10 on the matching section of the pretest. This group had taken an average of 1.08 biology courses. Forty-nine participants scored a 10 or higher on the pretest matching section; however, one of those participants did not report the number of biology courses taken and was excluded from further analysis. The remaining 48 reported having taken an average of 1.85 biology courses. A two-tailed Mann-Whitney U test was used to evaluate the hypothesis that there were differences in the number of biology courses taken between the two groups. The Mann-Whitney U test was used because the number of biology courses taken was not normally distributed. The results of the test were statistically significant, z=-2.95, p<0.05. The group that scored 10 or higher on matching had a mean rank of 94.25 and the group that scored nine or lower on matching had an average rank of 73.06. These results indicated that the number of biology courses taken prior to participating in this project was related to students' scores on the pretest matching section within the larger sample.

Planning

A two-tailed Mann-Whitney U test was used to evaluate the hypothesis that there were differences between the two groups in the frequency that students planned. The Mann-Whitney U test was used because the macro-level SRL process variable planning was not normally distributed. The results of the test were not statistically significant, z=-1.16, p=0.246. The conceptual understanding group had an average rank of 33.75 and the declarative knowledge group had an average rank of 28.38.

Strategy Use

Two separate macro-level variables were calculated in order to fully test the hypothesis that there were significant differences in the frequency with which students employed strategies between students that gained only declarative knowledge and students that reached a conceptual understanding. The first variable, strategy use, was calculated by adding all occurrences of the micro-level processes that are part of the macro-level process strategy use. The second variable, strategy use without SNIS, was calculated by adding the occurrences of all micro-level processes listed as part of strategy use except Select New Information Source (SNIS). This variable was calculated to eliminate the potential effect that SNIS could have on data analysis. Students frequently conduct the micro-level SRL process select new information source. Selecting new information source is a strategy, but it is a very low-level strategy. Frequent use of SNIS is an indicator of poor use of SRL. Participants that overuse SNIS are frequently moving rapidly and haphazardly through the environment. For this reason, it was removed from the analysis.

An independent-samples t test was conducted to evaluate the hypothesis that there was a difference in the frequency with which students used strategies between the two groups. The result of Levene's Test for Equality of Variances, F=0.19, p=0.657, was not statistically significant and indicated that equal variances could be assumed. The t-test was not statistically significant, t (60) =0.878, p=0.657. The 95% confidence interval for the difference in means ranged from -7.3 to 18.6.

Using the strategy use without SNIS variable, an independent-samples t-test was conducted to evaluate they hypothesis that there was a difference in the frequency with which students used strategies between the two groups when the micro-level process SNIS was not included. The result of Levene's Test for Equality of Variances, F=0.00, p=0.992, was not statistically significant and indicated that equal variances could be assumed. The t-test was not statistically significant, t (50.5) =0.864, p=0.39. The 95% confidence interval for the difference in means ranged from -6.01 to 20.0.

Monitoring

A two-tailed Mann-Whitney U test was used to evaluate the hypothesis that there were differences in the frequency that students monitor progress between the two groups. The Mann-Whitney U test was used because the macro-level SRL process variable was not normally distributed. The results of the test were not statistically significant, z=-0.85, p=0.395. The conceptual understanding group had an average rank of 33.15 and the declarative knowledge group had an average rank of 29.21.

Task Difficulty and Demands

A two-way contingency table analysis was conducted to evaluate whether there was a statistically significant difference between the number of times participants in the conceptual understanding group and participants in the declarative knowledge group monitored task difficulty and demands. The contingency table analysis was selected after reviewing the distribution of the task difficult and demand variable. The scores on this variable resembled a binomial distribution: a subset of the participants monitored task difficulty once, and the remaining students did not monitor task difficulty at all. There was no statistically significant relationship between group and frequency of monitoring task difficulty and demand, Pearson χ^2 (1, N=62) =0.096, p=0.757, *Cramer's V*=0.039. Thirty-four participants in the conceptual understanding group (N=36) monitored task difficulty and demands zero times while two participants did it once. Twenty-five participants in the declarative knowledge group (N=26) monitored task difficulty and demands zero times and one participant monitored task difficulty and demands once.

Interest

The macro-level SRL process interest was calculated by subtracting the number of times each student used the micro-level process INT- from the number of times the student used the micro-level process INT+. This was done so that the macro-level variable interest captured a student's overall level of interest. For example, a student that made two positive interest comments and three comments about not being interested or bored received an overall interest score of negative one.

A two-tailed Mann-Whitney U test was used to evaluate the hypothesis that there were differences in the interest level of students between the two groups. The Mann-Whitney U test was used because the macro-level SRL process variable interest was not normally distributed. The results of the test were not statistically significant, $z=-1.99$, $p=0.047$. This value was not significant because the Holm's sequential Bonferonni adjustment required a p value less than 0.01 for significant results. The conceptual understanding group had an average rank of 35.29 and the declarative knowledge group had an average rank of 26.25.

Summary

This project examined differences in the use of macro-level SRL processes between two groups. One group consisted of participants that gained only declarative knowledge about a complex topic while learning in a hypermedia environment. The other group contained participants that reach a conceptual understanding of the complex topic. Overall, these results indicated there is not a statistically significant difference in the frequency with which students employ macro-level SRL processes between students in the two groups.

Discussion

The intent of this project was to contribute to research regarding the use of self-regulated learning processes in hypermedia environments. The goal was to identify differences in the SRL processes employed by students that reached a conceptual understanding when compared with students that gained only declarative knowledge from the same learning task. Specifically, I sought to investigate differences in the frequency that students employed the five macro-level SRL processes: planning, strategy use, monitoring, task difficulty and demands, and interest. Statistically and practically significant results from this study would have helped educators and creators of hypermedia environments in the future by identifying particular SRL processes that potentially contribute to students' ability to reach a conceptual understanding. Educators would benefit from this analysis because identifying these macro-level processes would allow them to emphasize and train students in the SRL processes that lead to conceptual understanding. Identification of these SRL processes would allow hypermedia developers to incorporate SRL learning processes into hypermedia learning environments.

A variation of Azevedo and colleagues' (Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie et.al., 2004; Azevedo, 2005; Greene & Azevedo, 2008) model of SRL was used to capture the self-regulated learning processes that students used while learning about the circulatory system in a hypermedia environment. This model captured students' SRL processes by labeling them with one of 31 micro-level SRL processes. For the purposes of this study, these micro-level processes were summed to generate a frequency for each of the five macro-level processes.

The research questions for this project concerned whether there were differences in the frequency with which the conceptual understanding group and the declarative knowledge group employed the macro-level SRL processes. The results of this study did not show statistically significant differences between the two groups in terms of use of the five macro-level processes.

The lack of statistically significant results from this study limits what can be generalized from this study. The results from this study are limited to similar populations of college students and cannot be applied to learners of different ages, sociocultural contexts or academic backgrounds. Additionally, these results apply only to learning the circulatory system with hypermedia environments and do not necessarily describe differences in the use of SRL while learning in the classroom or learning different topics.

Limitations

This study focused on a relatively homogeneous group of academically successful college students. It is possible that within a more diverse group of students there could be differences in the frequency that SRL processes are employed between the two groups. For example, diversity in the group could be increased by studying students of different ages, sociocultural backgrounds, or with more diverse academic achievement. Additionally, the relatively small sample size for this project may have reduced the power of the analysis and precluded statistically significant results.

The two groups for this project, declarative knowledge only and conceptual understanding, were created using a variation of the Azevedo and colleagues' mental model scoring rubric (Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie et.al., 2004; Azevedo, 2005; Greene & Azevedo, 2008). The results of this study should be applied only to groups created using similar rules. Changes in the criteria for inclusion in either the declarative knowledge or the conceptual understanding group might alter the results. The conceptual understanding group was created by selecting only students that reached a high mental model according the Azevedo and colleagues' rubric. Students that reached either a low or an intermediate mental model were placed in the declarative knowledge group. It is possible that splitting the groups at a different point on the mental model continuum would yield different results. For example, there may be significant differences in the frequency of the use of macro-level SRL processes between students that reach only a low mental model of the circulatory system and students that reach an intermediate mental model. Understanding this divide would still be useful for educators and designers of hypermedia learning environments. It is also possible that altering the requirements for the declarative knowledge group would change the results. For this study, a minimum change between pretest and posttest of four was required for inclusion. Raising or lowering this value would alter the sample of students included and might change the findings considerably.

This study focused on participants' use of macro-level SRL processes as opposed to micro-level SRL processes. This was a conscious choice designed to capture overall trends in the use of SRL processes. However, the key distinction between this study and previous studies was the comparison of the participants that gain only declarative knowledge and those that reach a conceptual understanding. Micro-level processes could be used instead of macro-level processes to answer similar questions about the differences in the use of SRL processes between learners in the two groups. Investigating differences between these two groups using micro-level SRL processes may identify important processes for further investigation that could aid both educators and hypermedia designers. As noted earlier, focusing on micro-level processes has the potential to block researchers' ability to see trends in SRL processes that may be seen using macro-level processes.

Directions for Future Research

While learning complex science topics in hypermedia environment some students reach a conceptual understanding of the topic while some gain declarative knowledge, but fail to reach a conceptual understanding. Science educators advocate that students reach a conceptual understanding of topics so they can apply what they learn to real world situations (Roth, 1990). Educators, students, and hypermedia designers will benefit from an understanding of what SRL processes distinguish students that reach a conceptual understanding from students that gain only declarative knowledge. Future research on the use of SRL processes to learn complex science topics in hypermedia environments should seek to identify differences between these two groups.

Future research into the differences in the frequency with which students that gain a conceptual understanding employ SRL processes might include a more diverse group of students. Further research might also divide students into groups at a different point along the conceptual understanding continuum defined by the Azevedo and colleagues model or alter the change in declarative knowledge required to participate in the study. Measuring SRL using the micro-level processes instead of the macro-level processes may alter results and lead to significant results.

Further research into difference between students that gain conceptual understanding and those that only gain declarative knowledge might also focus on learning in different environments. This study focused specifically on learning a complex science topic while using a hypermedia environment alone and in a lab. Hypermedia has many advantages for learning complex science topics and is employed in classroom settings today. Future research might explore differences in students' use of SRL in more authentic environments.

Conclusion

The statistical analyses for this project did not identify any differences in the frequency participants in the conceptual understanding group employed macro-level SRL processes when compared with participants in the declarative knowledge group. However, determining if students that reach a conceptual understanding while using a hypermedia environment employ SRL processes differently than other students has real world implications in classrooms and for software designers. Science education in today's classrooms requires that students reach a conceptual understanding of complex topics. Hypermedia learning environments can assist students as they seek a conceptual understanding of these complex topics. Self-regulated learning skills can assist learners as they learn complex science topics using hypermedia. Continued research into the self-regulated learning processes that assist students in their quest for a conceptual understanding will aid educators in the future.

Appendix A: Self-Regulated Learning Processes

Classes, Descriptions and Examples of the Macro- and Micro-Level Processes Used to Code Students' Regulatory Behavior (based upon Azevedo, Moos, Greene, Winters, & Cromley, 2008)

Macro-Level Process: Planning		
Micro-Level Processes	*Description*[1]	*Student Example*
Planning (Plan)	Stating two or more sub-goals simultaneously or stating a sub-goal and combining it with a time requirement.	"First I'll look around to see the structure of environment and then I'll go to specific sections of the circulatory system"
Sub-Goal (SG)	Learner articulates a specific sub-goal that is relevant to the experiment provided overall goal. Must verbalize the goal immediately before taking action.	"I'm looking for something that's going to discuss how things move through the system"
Recycle Goal in Working Memory (RGWM)	Restating the goal (e.g., question or parts of a question) in working memory	"…describe the location and function of the major valves in the heart"

Macro-Level Process: Monitoring		
Micro-Level Processes	*Description*	*Student Example*
Content Evaluation (Plus and Minus)[2] (CE+/-)	Monitoring content relative to goals. Learner states content is or is not useful toward reaching the goal.	"I'm reading through the info but it's not specific enough for what I'm looking for"
Expectation of Adequacy of Content (Plus and Minus) (EAC+/-)	Expecting that a certain type of representation will prove either adequate or inadequate given the current goal	"…the video will probably give me the info I need to answer this question" or "I don't think this section on blood pressure will answer my question"
Feeling of Knowing (Plus and Minus) (FOK+/-)	Learner is aware of having read something in the past and having some understanding of it, but not being able to recall it on demand or learner states this is information not seen before	"… I recognize that from the pretest…" or "artherosclerosis – I never heard that word before."

[1] All codes refer to what was recorded in the verbal protocols (i.e., read, seen, or heard in the environment and/or during discussions).

[2] Plus and minus indicates that there are two separate codes. Plus is used when a participant notes the presence of the attribute and minus is used when the participant notes the absence of the attribute i.e., Content Evaluation (-) when the content is deemed not helpful by the participant.

Judgment of Learning (Plus and Minus) (JOL+/-)	Learner makes a statement that they understand what they've read or becomes aware that they don't know or understand everything they read	"I get it" or "I don't know this stuff, it's difficult for me"
Monitor Progress Toward Goals (MPG)	Assessing whether previously-set goal has been met.	"Those were our goals, we accomplished them"
Monitor Use of Strategies (MUS)	Participant comments on how useful a strategy was	"Yeah, drawing it really helped me understand how blood flow throughout the heart"
Time Monitoring (TM)	Participant refers to the number of minutes remaining	"I only have 3 minutes left"
Task Difficulty (TD)	Learner indicates the task is hard or easy.	"This is harder than reading a book."

Macro-Level Process: Strategy Use

Micro-Level Processes	*Description*	*Student Example*
Control Video (CV)	Using pause, start, rewind, or other controls in the digital animation	Clicking pause during the video
Coordinating Informational Sources (COIS)	Coordinating multiple representations, e.g., drawing and notes.	"I'm going to put that [text] with the diagram"
Draw (DRAW)	Making a drawing or diagram to assist in learning	"…I'm trying to imitate the diagram as best as possible"
Inferences (INF)	Making inferences based on what was read, seen, or heard in the hypermedia environment	…[Learner sees the diagram of the heart] and states "so the blood….through the …then goes from the atrium to the ventricle… and then…"
Knowledge Elaboration (KE)	Elaborating on what was just read, seen, or heard with prior knowledge	[after inspecting a picture of the major valves of the heart] the learner states "so that's how the systemic and pulmonary systems work together"
Memorization (MEM)	Learner tries to memorize text, diagram, etc.	"I'm going to try to memorize this picture"
Prior Knowledge Activation (PKA)	Searching memory for relevant prior knowledge either before beginning performance of a task or during task performance	"It's hard for me to understand, but I vaguely remember learning about the role of blood in high school"
Read Notes (RN)	Reviewing learner's notes.	"Carry blood away. Arteries—away."
Re-reading (RR)	Re-reading or revisiting a section of the hypermedia environment	"I'm reading this again."
Search (SEARCH)	Searching the hypermedia environment with or without the Encarta search feature	"I'm going to type blood pressure in the search box"

Selecting a New Informational Source (SNIS)	The selection and use of various cognitive strategies for memory, learning, reasoning, problem solving, and thinking. May include selecting a new representation, coordinating multiple representations, etc.	[Learner reads about location valves] then switches to watching the video to see their location
Summarization (SUM)	Summarizing what was just read, inspected, or heard in the hypermedia environment	"This says that white blood cells are involved in destroying foreign bodies"
Taking Notes (TN)	Copying text from the hypermedia environment	"I'm going to write that under heart"
	Macro-Level Process: Task Difficulty and Demands	
Micro-Level Processes	*Description*[2]	*Student Example*
Help Seeking Behavior (HSB)	Learner seeks assistance regarding either the adequateness of their answer or their instructional behavior	"Do you want me to give you a more detailed answer?"
	Macro-Level Process: Interest	
Micro-Level Processes	*Description*	*Student Example*
Interest Statement (Plus and Minus) (INT+/-)	Learner has a certain level of interest in the task or in the content domain of the task	"Interesting", "This stuff is interesting"

Appendix B: Blank Pretest

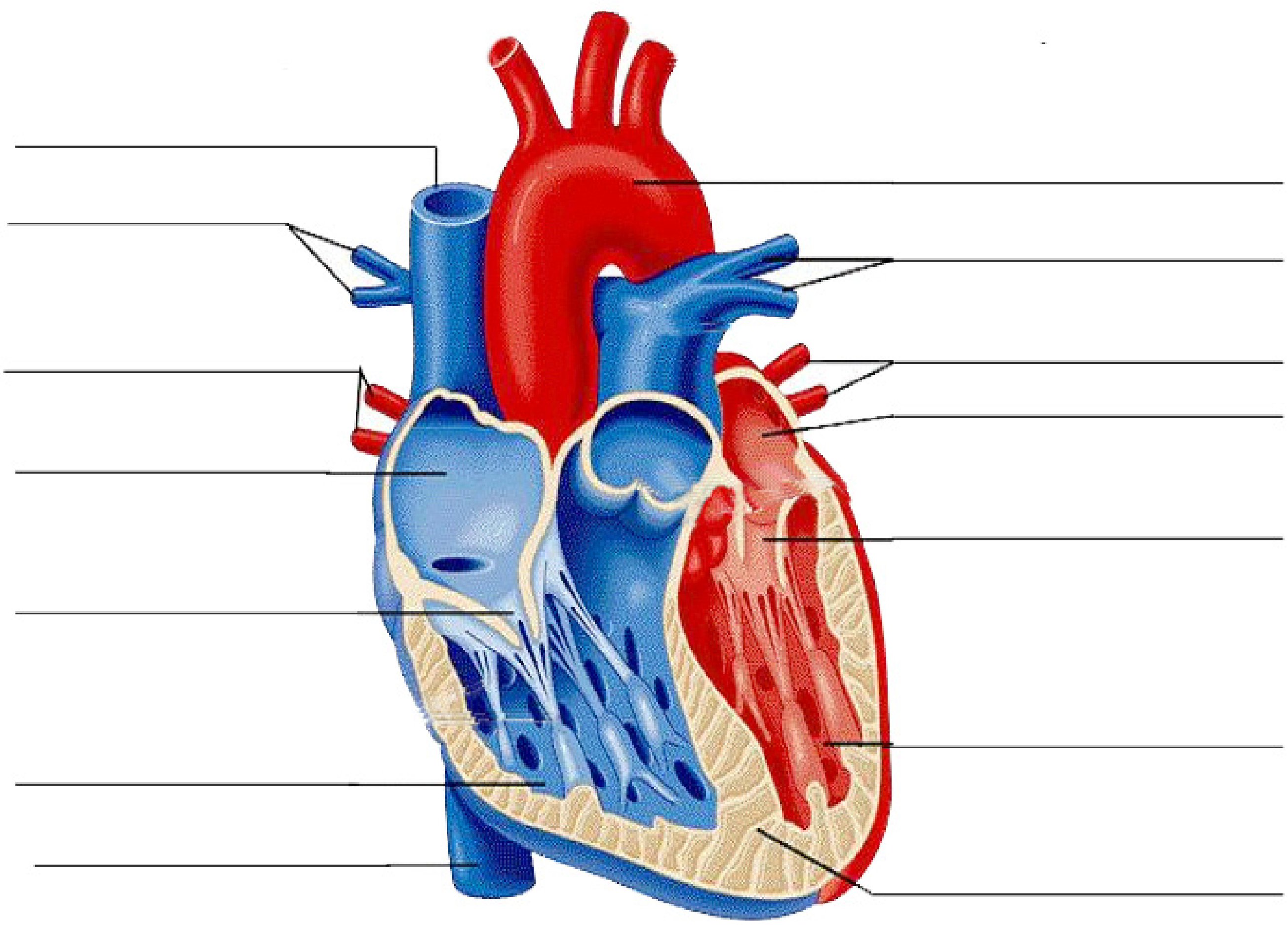
Pretest
Participant ID: ______________
Date:______________________

MATCH AS MANY COMPONENTS OF THE HEART AS YOU CAN
(13 points)

1. Valve	_____	A muscular pump that circulates blood throughout the body
2. Ventricle	_____	The fluid that circulates through the heart and blood vessels
3. Vein	_____	Pattern of blood flow through the lungs
4. Heart	_____	The main organ that supplies the blood with oxygen
5. Lung	_____	A muscular chamber that pumps blood out of the heart
6. Pulmonary Circulation	_____	A structure which keeps blood from flowing backwards within the circulatory system
7. Aorta	_____	The impulse-generating tissue located in the right atrium. The normal heartbeat starts here
8. Atrium	_____	Thin-walled vessel that carries blood back toward the heart
9. Artery	_____	Smallest blood vessel in the body
10. Capillary	_____	Largest artery in the body; carries blood from the left ventricle of the heart to the thorax and abdomen
11. Blood	_____	Thick-walled, elastic vessel that carries blood away from the heart to the arterioles
12. Pacemaker	_____	Flow of blood from left ventricle through all organs except the lungs
13. Systemic Circulation	_____	Chamber of the heart that receives blood from veins and pumps it to the ventricle on the same side of the heart

Pretest
Participant ID: _____________
Date:_____________________

LABEL AS MANY COMPONENTS OF THE HEART AS YOU CAN
(14 in total)



Pretest
Participant ID: _____________
Date:_____________________

PLEASE WRITE DOWN 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.

______Please use the back of this sheet if you need more space….

Appendix C: Mental Models

Necessary Features for Each Type of Mental Model (From Greene & Azevedo, 2008)

<u>Low Mental Model Category</u>

1. No understanding

2. Basic Global Concepts

- blood circulates

3. Global Concepts with Purpose

- blood circulates
- describes “purpose” - oxygen/nutrient transport

4. Single Loop – Basic

- blood circulates
- heart as pump
- vessels (arteries/veins) transport

5. Single Loop with Purpose

- blood circulates
- heart as pump
- vessels (arteries/veins) transport
- describe “purpose” - oxygen/nutrient transport

6. Single Loop - Advanced

- blood circulates
- heart as pump
- vessels (arteries/veins) transport

describe “purpose” – oxygen/nutrient transport

- mentions one of the following: electrical system, transport functions of blood, details of blood cells

Intermediate Mental Model Category

7. Single Loop with Lungs

- blood circulates
- heart as pump
- vessels (arteries/veins) transport
- mentions lungs as a “stop” along the way
- describe “purpose” – oxygen/nutrient transport

8. Single Loop with Lungs - Advanced

- blood circulates
- heart as pump
- vessels (arteries/veins) transport
- mentions Lungs as a "stop" along the way
- describe “purpose” – oxygen/nutrient transport
  mentions one of the following: electrical system, transport functions of blood, details of blood cells

High Mental Model Category

9. Double Loop Concept

- blood circulates
- heart as pump
- vessels (arteries/veins) transport
- describes “purpose” - oxygen/nutrient transport
- mentions separate pulmonary and systemic systems
- mentions importance of lungs

10. Double Loop – Basic

- blood circulates
- heart as pump
- vessels (arteries/veins) transport
- describe “purpose” - oxygen/nutrient transport
- describes loop: heart - body - heart - lungs - heart

11. Double Loop – Detailed

- blood circulates
- heart as pump
- vessels (arteries/veins) transport
- describe “purpose” - oxygen/nutrient transport
- describes loop: heart - body - heart - lungs – heart
- structural details described: names vessels, describes flow through valves

12. Double Loop - Advanced

- blood circulates
- heart as pump
- vessels (arteries/veins) transport
- describe “purpose” - oxygen/nutrient transport
- describes loop: heart - body - heart - lungs - heart
- structural details described: names vessels, describes flow through valves
- mentions one of the following: electrical system, transport functions of blood, details of blood cell

Appendix D: Sample Page of a Coded Transcript

worried about how it works, how it doesn't work…not how it doesn't work. /All right, let's go — Plan
take a look at blood, and see if we can get anything in the last couple of minutes./*Blood* — SNIS (SNIS)
vital fluid found in humans and other animals that provides important nourishment to all body
organs and tissues and carries away waste materials./O.K. Circulatory system../*5 to 6 liters in* — NC
an adult human. .. 7 to 8 percent of body weight./Interesting facts. /*Role of Blood.* /O.K. — INT+
Better jot a couple of things down right here. Blood. There will be blood./The *Role of Bood.* — TN
carries oxygen from the lungs/We know about that./After it helps ….taking….digestive — FOK+
system…O.K. Metabolism…uh, waste…the kidneys../*responsible for activities of the immune* — NC
system. (98.6° F)./*55% plasma,*/which, as I recall, is a yellowish liquidy material./ Um….*Red* — TN PKA
Blood Cells…45%...*Blood Type* ../I'm not really concerned with that right now./.*Immune* — CE–
System../nahhh….All right. Blood…is not as much as I thought./I might go take a look back at — NC
the ….circulatory system… the last couple of minutes./Let me take a look at the media again./ — Plan SNIS
Um…uh…what is this? …../ — (SNIS) NC

Experimenter: Keep telling us what you're thinking.

Participant:/All righty. Uh...I'm taking a look at the heart valve…diagram./It's broken down into — NC
the valve, to keep blood from flowing backwards./We know that./Uh…Not too interesting. / — SUM JOL+
/Let's go back, to the components of the circulatory system, and a couple of the things that help — INT-
transfer the blood./ All right. Arteries, capillaries…I got that down./ Um…oooh, arteries have — SNIS FOK+
thicker walls than the veins, to withstand the pressure of blood being pumped from the heart./ — Reading
I'm gonna make a note of that. Arteries…thicker walls…have thicker walls…than the veins, — TN
because…umm….Why was that again? Oh, yeah. They're thicker to keep the blood flowing
back to the heart./There's the lungs….side bars…What is this? Open../.Looks like an article, — SNIS TM
that with 10 minutes left,/I'm not interested in reading./*Systematic Circulation*./.I think we — INT- SNIS

Notes:

1. See Appendix A for code descriptions and abbreviations.
2. Items in italics are direct reads from the hypermedia environment and are not coded.
3. Slash marks indicate the beginning and end of a coded segment.

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