AN INVESTIGATION OF THE ROLE OF METACOGNITIVE BEHAVIOR IN SELF-REGULATED LEARNING WHEN LEARNING A COMPLEX SCIENCE TOPIC WITH A HYPERMEDIA LEARNING ENVIRONMENT

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A thesis proposal submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Master of Arts in Educational Psychology, Measurement and Evaluation in the School of Education.

Chapel Hill
2011

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ABSTRACT

Banu Binbasaran-Tuysuzoglu: An Investigation of the Role of Metacognitive Behavior in Self-Regulated-Learning When Learning a Complex Science Topic with a Hypermedia Learning Environment
(Under the direction of Dr. Jeffrey A. Greene)

Studies have shown that learners need to use self-regulated learning (SRL) skills when learning with Hypermedia Learning Environments (HLEs) to reach a conceptual understanding of science. SRL theory suggests that metacognition plays a key role in learning. The aim of this study was to investigate the relationship between metacognitive monitoring (e.g., judgment of learning [JOL]) and metacognitive control and their effects upon learning about the circulatory system with an HLE. I examined the frequencies of learners’ use of negative JOL with and without a change in strategy use, which indicates the quality (i.e., static or adaptive) of metacognitive behavior. The results showed that adaptive metacognitive behavior positively related to learning, and static metacognitive behavior negatively related to learning, above and beyond the effect of prior knowledge. Findings provided valuable implications for the benefits of using JOL followed by control over strategy use when learning with HLEs.
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CHAPTER 1
INTRODUCTION

Computer-based learning environments (CBLEs) are becoming widely used in education (Azevedo, 2005). This widespread use of CBLEs, such as hypermedia learning environments (HLEs), offers the potential to enhance learners’ understanding of complex science topics (Azevedo, Cromley, & Seibert, 2004). HLEs are tools that include hyperlinked resources. They have the capacity to hold multiple representations of information including video, audio, diagrams, text, and animations that are interwined to create a non-linear medium of information. With this structure, HLEs allow learners to control which of those representations to access, and in what order to access them to support their learning. Other CBLEs, like multimedia, present multiple representations as well, but they do not necessarily allow user control. Therefore, HLEs offer more control over the instructional environment to the learners than other kinds of CBLEs.

There have been many studies conducted to investigate how HLEs can help learners learn about complex science topics (Winters, Greene, & Costich, 2008). Despite the educational potential of HLE, research has shown that learners struggle to control their learning in HLE (Azevedo, Guthrie, & Seibert, 2004). To be effective, HLEs require that learners be able to actively and thoughtfully control all of the multiple representations available to them (Azevedo, 2005). This means that learners need to engage in self-regulated
learning (SRL; Zimmerman, 2000) processes, including monitoring and control (Azevedo, 2005). Research has indicated that learners who use SRL processes more frequently learn better in HLE than learners who use SRL processes less often (Azevedo & Cromley, 2004; Azevedo, Guthrie, et al., 2004; Greene & Azevedo, 2007a). Thus, SRL has become more important with the increased use of HLEs for learning in schools.

SRL is “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” (Pintrich, 2000, p. 453). As the definition indicates, SRL requires active engagement and goal-directed behavior. Among various SRL models, Winne and Hadwin’s (1998) model has been widely used in studies of learning with HLEs. In their model, Winne and Hadwin adopted an information processing theory approach to SRL, outlining the cognitive and metacognitive processes that occur during learning. According to Winne and Hadwin, SRL has three necessary phases and an optional fourth phase (see Appendix A). SRL begins with phase one: defining the task. In this phase, the learner constructs a personalized understanding of the task from two sources: task conditions (i.e., resources, instructional cues, time, and the local context) and cognitive conditions (i.e., beliefs, dispositions, styles, motivation, domain knowledge, knowledge of the current task, and knowledge of study tactics and strategies). On the basis of self-generated perceptions of the task in phase one, self-regulating learners set learning goals in phase two. Once goals are framed, tactics or strategies stored in learners' long-term memory are activated to meet those goals in phase three. In phase four learners have the opportunity to adapt schemas that configure how SRL
will proceed in similar future tasks (e.g., adjusting conditions that determine when a tactic is appropriate).

According to Winne and Hadwin (1998), metacognition is a key feature of SRL. Metacognition has two basic components, metacognitive monitoring and metacognitive control (Winne, 1996). Metacognitive monitoring is a cognitive evaluation that relies on learners' subjective judgments of the adequacy of learning. Metacognitive control occurs when learners adjust how they are engaging in learning, based on the results from metacognitive monitoring (Winne, 2001). Within each of the four phases described above, learners engage in metacognitive monitoring. The results of that monitoring (e.g., mismatch of learning outcomes and goals) can prompt the learner to enact metacognitive control. This metacognitive behavior, along with all other aspects of SRL, helps learners regulate their learning. Learners must monitor, regulate, and control their own learning process in relation to their learning goal when studying with a HLE (Azevedo, Moos, Greene, Winters & Cromley, 2008).

Researchers have studied SRL in the context of HLEs, and they have recognized that using SRL processes is an important factor when learning complex science topics (Azevedo, Cromley, Winters, Moos, & Greene, 2005; Azevedo, Guthrie et al., 2004; Azevedo, Greene, & Moos, 2007; Greene, Costa, Robertson, Pan, & Deekens, 2010). SRL researchers have also examined the effects of monitoring, an important component of metacognition, upon learning (e.g., Azevedo et al., 2005; Azevedo, Guthrie et al., 2004; Azevedo & Witherspoon, 2009; Moos & Azevedo, 2006, 2008, 2009). However no one has studied metacognitive behavior in terms of whether metacognitive control, enacted as a result of monitoring, is predictive of learning. Apart from SRL research, there are some metacognition researchers that have
focused on how metacognitive behavior affects study-time allocation (Son & Metcalfe, 2000), and the effectiveness of metacognitive behavior in an experimental recall task (Thiede, Anderson, & Therriault, 2003). These researchers did not investigate the effect of metacognitive behavior on academic performance. In this study, my purpose was to investigate the relation between metacognitive monitoring and control and its effect on academic performance when learning a complex science topic with HLE.

As noted above, Winne and Hadwin’s (1998) SRL model illustrated how metacognitive monitoring and metacognitive control relate to SRL. Metacognitive monitoring produces a subjective judgment of learning that can lead to metacognitive control. Judgments of learning (JOL) are learners’ judgments about how well they have learned particular information (Koriat, 2007). This subjective judgment can initiate metacognitive control, which can involve changing from one strategy to another one. SRL theory, therefore, suggests that accurate subjective judgments about the fit of learning products to standards should yield appropriate strategy changes, and the frequency of this metacognitive behavior should predict academic performance (Winne, 2004). Good metacognitive control involves changing from an ineffective strategy to a more effective one. When prior strategies have not worked well, the student should make a negative JOL and then change the strategy. For example, when learners make a judgment that they do not understand what was just read, a negative JOL, they should enact another learning strategy such as re-reading, note taking, drawing, etc. In this study, I treated negative JOL as a monitoring process, and looked for a change in strategy as an indicator of an adaptive metacognitive behavior. If there was no strategy change following the negative JOL, I counted this as an instance of static metacognitive behavior. To determine whether adaptive
and static metacognitive behavior related to learning, I conducted a secondary analysis of think-aloud protocol (TAP) data for instances of adaptive metacognitive behavior. I also included static metacognitive behavior in the analysis to differentiate its effect upon learning from the effect of adaptive metacognitive behavior. Then I examined whether the frequencies of coded adaptive and static metacognitive behavior predict learning outcomes.

My research questions were:

1. Does the frequency of negative JOL followed by a change in strategy use (i.e., adaptive metacognitive behavior) predict posttest conceptual understanding of a complex science topic with HLE, after controlling for pretest prior knowledge?

2. Does the frequency of negative JOL not followed by a change in strategy use (i.e., static metacognitive behavior) predict posttest conceptual understanding of a complex science topic with HLE, after controlling for pretest prior knowledge?
CHAPTER 2
LITERATURE REVIEW

In this study, I focused on learning a complex science topic, the circulatory system, with HLEs. Studies have shown that due to their non-linear nature, learners need to self-regulate their learning with HLEs (Azevedo, 2005; Azevedo, Guthrie et al., 2004; Greene & Azevedo, 2007a). This information is important because studies have also shown that HLEs are becoming increasingly prevalent in the teaching and learning of complex science topics (Azevedo, 2005). Learners who do not self-regulate their learning effectively will not learn as well from HLEs as the ones who do self-regulate their learning effectively (Azevedo, Guthrie et al., 2004; Greene & Azevedo, 2007a; Greene et al., 2010). Therefore, it is important to understand how self-regulated learning (SRL) functions. The aim of this study was to investigate metacognitive behavior, which includes two key components of SRL, monitoring and control, as predictors of learning with HLEs. Thus, in this chapter, I briefly explain the use of HLEs as learning tools, how SRL facilitates learning with HLEs, and the role of metacognitive behavior in SRL. Also, I review empirical evidence on how metacognitive behavior relates to learning, as well as the measurement of SRL.

Hypermedia as a Learning Tool

Many science topics are complex systems that have multiple interconnected components (Hmelo-Silver & Azevedo, 2006). Such systems cannot be explained exclusively
by describing their isolated components because they also include the interactions of the
components. For example, in the human circulatory system, multiple components such as the
chambers and valves of heart, arteries and veins of various sizes function simultaneously
while interacting with each other and the other systems of the body. Learners need to know
both how the parts work and also how they work together. Memorization of the isolated
components of the system leads to little understanding of how the whole system works
(Hmelo-Silver & Azevedo, 2006). Learners need to integrate knowledge of anatomy, the
function of each component, and their interactions to construct a conceptual understanding of
how the circulatory system works.

Constructing a conceptual understanding of complex systems is usually difficult for
learners when the components of the system are not physically available for studying.
Representations including text, videos, diagrams, and graphs could help learners learning
about complex systems (Hmelo-Silver & Azevedo, 2006). Therefore CBLEs, such as HLEs,
seem ideal for learning such topics. In HLEs, graphics, audio, video, plain text,
and hyperlinks intertwine to create a non-linear medium of information (Conklin, 1987).
Different types of information can be displayed in various ways in HLEs. Readers can
dynamically access these various kinds of representations of information, usually by a mouse
click. This capacity of HLEs enables learners to control their own learning process (Scheiter
& Gerjets, 2007). Learners can select and sequence information according to their personal
needs and preferences. This control can increase learners’ interest and motivation, facilitate
adaptive instruction, or provide affordances for active and constructive information
processing (Scheiter & Gerjets, 2007).
Problems of Learning with Hypermedia

Surprisingly, the research has yielded mixed results, and it has been argued that HLEs’ features, which may be effective tools for fostering learning, can also be detrimental for some learners (Scheiter & Gerjets, 2007). Scheiter and Gerjets stated that this could be either due to usability problems (e.g., disorientation, distraction, cognitive overload), or learner characteristics (e.g., prior knowledge, self-regulatory skills, cognitive styles, and attitudes towards learning). Difficulties in learning with HLEs might also be caused by bad instructional design. Some of these difficulties can be overcome by technological advancements; however, other problems are inherent to HLEs. The only way to overcome these difficulties is to prepare learners with the skills and knowledge they need to learn successfully with HLEs (Scheiter & Gerjets, 2007).

Providing learners with flexible access and a high degree of user control in non-linear HLEs can lead to disorientation and distraction (Scheiter & Gerjets, 2007). For example, the ease of browsing might increase the risk that the learner moves too quickly through the material, thus gaining only a superficial understanding of the subject. Also, learners could become disoriented, resulting in confusion rather than understanding, especially if the learners select links in a more or less random manner.

Cognitive overload is another usability problem of learning with HLEs (Scheiter & Gerjets, 2007). Closely related to disorientation problems, cognitive overload refers to the additional effort and concentration necessary to engage in complex or multiple tasks (Sweller, 1988). Working memory is the system in the brain that handles the temporary storage and processing of new information (Baddeley, 2001). It draws on knowledge (i.e., declarative, procedural, and self-regulatory [Schraw, 2006]) already stored in long-term
memory 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 be deleterious, causing cognitive overload. According to Cognitive Load Theory (Sweller, 1988), difficulties in information selection, information sequencing, and pacing may result because of cognitive overload. In HLEs, learners must navigate the environment while simultaneously planning what content areas to investigate, how to manage time, and what goals are important (Greene & Azevedo, 2007a). Making decisions as to which links to follow and which to abandon can cause overload when learning with HLEs. Even the process of pausing, either to take notes about required information or to decide which link to select next, can be very distracting. Cognitive overload can become a serious problem if there are a large number of nodes and links. The constant processing required when learning with a HLE places increased demands on learners’ working memory and ultimately can interfere with learning.

According to Scheiter and Gerjets (2007), the amount of learners’ prior knowledge can moderate the relationship between self-regulatory skills and learning with HLEs. Researchers have shown that learners with low levels of prior knowledge, in comparison to learners with high levels of prior knowledge, have more difficulties learning with HLEs (Greene et al., 2010). A comprehensive overview of the studies investigating the relationship between prior knowledge and HLE effectiveness was provided by Chen and colleagues (2006). They concluded in their review that learners with high prior knowledge do not require additional support in handling the HLEs, are able to choose flexibly between different ways of accessing information, and benefit only from those navigational tools (e.g., search engines) that help to locate specific information. Less knowledgeable students, however,
require additional support (Chen, Fan, & Macredie, 2006). Scheiter and Gerjets (2007) proposed an explanation rooted in schema theory for these findings. Learners with abundant prior knowledge are better able to make schema-driven selections, because they can accurately identify knowledge needs a priori and make their selection accordingly. By contrast, those with limited prior knowledge cannot identify information needs in advance, thus their selections are less schema-driven and therefore less productive.

Likewise, using self-regulatory skills can moderate the relationship between prior knowledge and learning with HLEs (Scheiter & Gerjets, 2007). Learners need to analyze the learning situation, set meaningful goals, determine which learning strategies to use, assess the effectiveness of enacted strategies in meeting the goal, and evaluate emerging understanding when studying with HLEs (Azevedo, 2005; Azevedo et al., 2008). These self-regulatory skills appear to be critical to facilitating learning in HLEs (Azevedo, 2005; Scheiter & Gerjets, 2007). SRL researchers have suggested that learners using a HLE to learn complex science topics perform better on subsequent assessments when they effectively employ SRL processes (Azevedo, Guthrie et al., 2004; Greene & Azevedo, 2007a; Greene et al., 2010).

**Self-Regulated Learning**

SRL is “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” (Pintrich, 2000, p. 453). As the definition indicates, SRL requires active engagement and goal-directed behavior. It involves goal setting and task analysis, implementation of the plan that was constructed, and self-evaluation of the learning process.
SRL has been studied from many different perspectives (Zimmerman, 2001). Among them, cognitive perspectives of SRL share some general assumptions: The self-regulated learner is an active, constructive person who sets goals for his or her learning and then attempts to monitor, regulate, and control his or her cognition, motivation, and behavior, guided and constrained by his or her goals and the contextual features in the environment (Azevedo, 2005; Pintrich, 2000; Winne & Hadwin, 1998; Zimmerman, 2001). Some researchers (e.g., Azevedo et al., 2007; Greene et al., 2010) use Winne and Hadwin’s (1998) model as their conceptual framework when they study how SRL skills relate to the effective use of HLEs.

Learners are not only active, but also proactive by self-regulating their own learning processes (Zimmerman, 2000). The purpose of education is not only to fill learners’ brains with information, but also to increase their awareness of their thinking skills, and to become effective problem solvers in the future. To achieve this aim, one of the most important things is to help learners to develop self-awareness. This awareness of their thinking also helps learners to think about the effectiveness of strategies, which they use for accomplishing their goals. Strategies are potentially conscious and controllable cognitive operations used to achieve cognitive purposes (Pressley, Pressley, Elliot-Faust, & Miller, 1985). Having strategies stored in learners’ memories, and making them self-aware of these strategies, facilitates their usage and therefore students’ learning.

People store many different types of knowledge in their memory. Each type serves a different purpose. According to Schraw (2006), the three main knowledge types are declarative, procedural, and self-regulatory. Declarative knowledge is knowledge of facts and concepts, whereas procedural knowledge is the knowledge of how to do things. Schraw
(2006) described declarative and procedural knowledge as the building blocks of the development of cognitive skills and expertise, however, without the support of self-regulatory knowledge even large amounts of declarative and procedural knowledge do not help people to survive and adapt (Zeidner, Boekaerts, & Pintrich, 2000; Zimmerman, 2000).

Self-regulatory knowledge includes metacognition, which is knowing about strategies and when to use a particular strategy, and knowing about regulatory skills such as planning, monitoring, and evaluation of learning (Schraw, 2006). Therefore, it is reasonable to conclude that knowledge about cognitive strategies and knowledge about when and where particular cognitive strategies should be used are important for effective learning (Pressley & Harris, 2006), and essential in the development of life-long learning skills. Life-long learning skills are self-regulatory skills learners need after graduation from high school or college, when they learn important skills informally (Zimmerman, 2001).

Winne and Hadwin (1998) explained learning by outlining the cognitive and metacognitive processes involved in their SRL model. They first introduced key components of learning (e.g., conditions, standards, cognitive and metacognitive operations, products, and evaluations) and then explained how these components interact during a four-phased learning session (i.e., defining the task, setting goals and planning, enacting tactics to approach goals, and adapting tactics) (Winne & Hadwin, 1998). Conditions include student characteristics and characteristics of the learning task. Operations are the information manipulation processes that occur during learning (e.g., strategy use). The output information resulting from operations is called a product. During learning, products are compared to standards using monitoring to determine if phase objectives have been met. Standards are multifaceted criteria including metrics for learning quality and learners’ beliefs. The comparison between
products and standards results in cognitive evaluations, which are determinations of whether the products have an acceptable fit with metrics for learning quality.

A learning session starts with the phase where the learner defines the task. In this phase, the learner constructs a personalized understanding of the task by processing information about the conditions that characterize an assigned task. There are two main sources of information used to define a task: task conditions and cognitive conditions. The former is situational information about the task. The latter, however, is information the learner retrieves from long-term memory (Winne, 2001). Teacher’s directions for a homework assignment are an example of task conditions. Learners’ estimates of prior domain knowledge, beliefs about their ability for success, and previous experiences in a similar task are examples of information provided by cognitive conditions. Based on these self-generated perceptions of the task in phase one, self-regulating learners set learning goals and plans in phase two. These processes are dynamic as goals can be updated as learners proceed through the learning task. During the third phase, learners set their plans into action by utilizing strategies and tactics stored in learners' long-term memory to meet those goals set in second phase. In this phase, work on the task itself is done. The fourth phase is optional. During fourth phase learners have the opportunity to adapt schemas that configure how SRL will proceed in similar future tasks.

According to the model, there also are two key events in SRL, metacognitive monitoring and metacognitive control. As noted earlier, monitoring is a process that compares two chunks of information. Metacognitive monitoring is a special form of monitoring (Winne, 2001). It provides opportunities to control the learning process to
effectively meet the learning goal. As such, metacognitive monitoring and control are keys to SRL (Winne, 2001).

Metacognitive Monitoring and Control in Self-Regulated Learning

Investigating the role of metacognitive behavior in SRL is the main purpose of this study. Therefore, it is necessary to review what is known about metacognition in relation to its role in SRL. In this section, I primarily focus on metacognition as the essential component of SRL.

Metacognition takes its roots from Flavell’s metamemory study (i.e., Flavell, 1971), which concerned the monitoring and control of learning and remembering (Koriat, 2007). Flavell (1976) was the first to use the word metacognition. He defined metacognition as “One’s knowledge concerning one’s own cognitive processes and products or anything related to them” (Flavell, 1976, p. 232). It includes knowing about strategies and when to use a particular strategy (Schraw, 2006). Winne (1996) described metacognition as a key component of SRL, with two basic components; metacognitive monitoring and metacognitive control. Within each of the four phases in the SRL model, learners engage in metacognitive monitoring to determine if the products of phase processing meet their standards. Metacognitive monitoring relies on learners' cognitive evaluations of learning. If there is a mismatch between the products of phase processing and the standards, self-regulating learners should engage in metacognitive control. Metacognitive control determines the progress of learning by deciding how to act, including changing the strategies selected for approaching the goal (Winne, 2001).

Winne explained the relation between metacognitive monitoring and control using the example of an IF-THEN-ELSE procedure: IF conditions are met, THEN enact a particular
tactic, ELSE use a different tactic (Winne, 2001). According to Winne (2001), this procedure sets the stage for exercising control in SRL. In this procedure, IF corresponds to a condition, THEN describes the activity coupled to particular configuration of IF, and ELSE stands for a different action. To engage in metacognition, first products are monitored relative to standards, which generates evaluations that update conditions. The updated conditions, then, may be coupled to a different action (Winne, 2004). For example, IF the memorized definition of a term matches the standard as indicated by a textbook, THEN continue memorizing terms, or ELSE change the strategy to taking notes and try to learn the term again. Thus, metacognitive monitoring is the key to SRL because it provides guidance about how to regulate learning.

As mentioned earlier, the output of monitoring is learners’ subjective judgment about products and processes that are monitored. According to Koriat (2007), metacognitive judgment is the core concept shaping metacognition research. Researchers have identified three main types of metacognitive judgments: confidence judgments, feelings of knowing judgments (FOK), and judgments of learning (JOL) (Koriat, 2007). A confidence judgment is subjective confidence in the correctness of the answer retrieved from memory or after selecting an answer. It reflects an assessment about a memory that has been produced. Feelings of knowing judgments are elicited following a failed retrieval. The learner is aware of having read something in the past and having some understanding of it, but is not able to recall it on demand. Therefore, it depends upon prior knowledge, an internal characteristic of the learner. JOLs are elicited during learning. They are people’s subjective judgments about how well they have learned particular information from the material. JOL and FOK judgments are prospective whereas confidence judgments are retrospective. Therefore, JOL
and FOK processes are two monitoring processes used in metacognition research to predict future cognitive performance.

For this current study, I believe that JOLs are an appropriate measure of metacognition and a likely predictor of learning with HLEs because they provide the opportunity to investigate the relationship between metacognitive monitoring and metacognitive control, as suggested by Winne and Hadwin (1998). Through JOLs, learners evaluate their current learning against their desired learning goal and then generate subjective judgments about current performance on recently studied materials (Nelson & Narens, 1994). Such a monitoring process is considered critical in SRL because learners rely on monitoring output to make decisions about regulating subsequent study activities (Winne, 2001). For example, when learners monitor their progress during an assigned task, the output of this monitoring could be a recognition that they either did or did not understand everything they had read; that is, their positive or negative judgments of learning. These subjective judgments lead to metacognitive control behavior (Nelson, 1996). For instance, if learners feel unclear (i.e., a negative JOL) about a chapter they just read, they may decide to change the strategy just used (i.e., just reading silently) and instead take notes as they reread in the HLE to enhance their understanding of the chapter. In another instance, they may feel confident (i.e., a positive JOL) about the section, and decide to continue using a particular strategy in the next chapter. In this current study, I will especially focus on negative JOLs. Theory suggests that good metacognitive control involves changing from an ineffective strategy to a more effective one. Therefore, negative JOLs indicate instances where effective learners should decide to metacognitively control their learning, and switch to a different strategy than the one used previously. This is what I call adaptive metacognitive behavior, and it is what I
investigated as a predictor of learning. Also, I included static metacognitive behavior, which I define as instances when participants did not change the strategy used before a negative JOL.

**Research on Metacognition in Relation with SRL**

SRL researchers have investigated the effect of monitoring, an important aspect of metacognition, on academic performance (i.e., Azevedo et al. 2005; Azevedo, Guthrie et al. 2004; Azevedo & Witherspoon, 2009; Moos & Azevedo 2006, 2008, 2009). Studies done by Azevedo and colleagues have revealed several monitoring processes that are necessary when learning with HLEs: judgment of learning (JOL) and feeling of knowing (FOK), which refers to monitoring learners’ emerging understanding, content evaluation (CE) which refers to monitoring the relevancy of the information in the environment, and monitoring the progress towards the learning goal. These studies have demonstrated that monitoring is important during learning with nonlinear environments, such as HLEs, because deploying monitoring better enables learners to control their learning in the HLEs (Greene & Azevedo, 2007a).

Another direction in the study of SRL is that specific monitoring processes may act as mediators between student characteristics and academic performance (Moos & Azevedo, 2009). For example, Moos and Azevedo conducted a study to examine the extent to which the relationship between self-efficacy and hypermedia learning outcomes was mediated by the use of specific monitoring processes. Their findings indicated that the relationship between self-efficacy and specific monitoring processes (i.e., monitoring understanding, monitoring environment, and monitoring progress towards goals) was significant. Also, they found that the relationship between self-efficacy and hypermedia learning outcomes was mediated by the extent to which participants monitored their understanding and the
environment. The relationship between prior domain knowledge and monitoring understanding was significant, as well. However, none of these studies included metacognitive control, enacted by monitoring, in their analyses, which I believe is important for a complete understanding of the effect of metacognitive behavior in SRL. As Winne (2001) stated, learners should adapt their strategies if a discrepancy is revealed through monitoring processes between the learning goal(s) and learners’ current knowledge state. Therefore, I believe that investigating metacognitive control (i.e., a strategy change), enacted by monitoring, is as critical as examining the effect of monitoring on learning outcomes.

Some studies principally investigated how people’s metacognitive judgments influence subsequent strategy use (Metcalfe, 2009; Son & Metcalfe, 2000; Thiede, Anderson & Therriault, 2003). Although these studies did not use SRL theory as a framework, they are relevant in that they primarily focused on how JOLs affected learners’ choice of strategy, specifically which items to restudy and how much time to allocate to each item. The results revealed that people were studying strategically based on their metacognition. However, these studies predominantly used rather simple learning materials such as paired associates, trigrams, factual statements, or categorized lists. The achievement tests focused on the recall of target words. However, learning at school or after school is much more complex than just remembering and retrieving information. These studies did not reveal a clear understanding of how metacognition functions when cognitive work beyond recall is involved in learning.

**Measuring SRL and Metacognition**

In many studies about SRL, researchers have used self-report measures (Duncan & McKeachie, 2005). For example, the Motivational Strategies for Learning Questionnaire (MSLQ; Pintrich, Smith, García, & McKeachie, 1991, 1993) is a self-report measure used to
evaluate student motivation and the application of self-regulated learning strategies. However, there are two issues challenging this method: accuracy and context. Duncan and McKeachie (2005) claimed that this measure can be considered reliable with coefficient alphas ranging from 0.62 to 0.93 for the first motivational scale and from 0.52 to 0.80 for the second learning strategy scale, although these ranges are too broad with minimum values too low to state confidently that MSLQ data were reliable. Other studies also showed that students do not accurately report the SRL processes they use during a learning event (Winne & Jamieson-Noel, 2002). Winne and Jamieson-Noel compared students' actual uses of tactics to their self-reports on study tactics. They found that students' perceptions of their uses of study tactics were inaccurate and overestimated.

Further, self-report instruments, including the MSLQ, require learners to respond to items in terms of general situations, rather than specific learning events. However, learning is a complicated event that occurs within a context. According to SRL theory, students strategically adapt their studying accordingly to different tasks or contexts (e.g., Winne & Hadwin, 1998). Therefore, these general self-report instruments, like the MSLQ, are unable to capture SRL as it occurs in different learning contexts.

As an alternative to self-report instruments, researchers have begun using online event measurement methodologies, such as think aloud protocols (TAPs; Ericson & Simon, 1993). Researchers using TAPs request that participants verbalize all of their thoughts and actions as they learn, to capture the traces of self-regulatory processes used during learning. These responses are later coded into SRL processes by trained researchers. These data, then, can be analyzed to determine qualitative and quantitative changes in SRL processes. Quantitative changes include the frequency of specific SRL processes that learners use
during learning, whereas qualitative changes can reveal conscious decisions that the learners make, such as changing the currently enacted SRL process to a different SRL process (Azevedo, Moos, Johnson, & Chauncey, 2010). TAPs have an open-ended structure with an unlimited response range that can reveal a vast amount of data. The data provide evidence for the presence, frequency, changes, and sophistication of SRL processes that are critical to explaining the role of these processes in learning with HLEs (Azevedo, Moos, Johnson, & Chauncey, 2010). With all of these features, the think-aloud methodology can be an effective way to assess students’ self-regulatory processes (Zimmerman, 2008).

One criticism of using TAPs to measure SRL is that participants’ verbalizations of their thoughts might disrupt their learning process. Empirical research, however, has shown that merely verbalizing thinking does not affect cognitive processing; rather it is when participants are asked to explain their thinking that there can be an effect upon their cognitive processing (Ericsson & Simon, 1993, 1998; Greene, Robertson, & Costa, 2011). Therefore, to ensure that using a think-aloud protocol does not disturb participants’ learning, they should be asked simply to verbalize but not to explain their actions.

Azevedo and his colleagues have developed an elaborate TAP for assessing learners’ self-regulated learning processes as an event. Their method was specifically designed to allow researchers to understand and measure self-regulated learning while learners learned about complex topics with HLEs. In their work (Azevedo, 2005; Azevedo, Cromley et. al., 2004; Azevedo, Guthrie et al., 2004; Greene & Azevedo, 2007a), they identified 35 SRL processes that they called micro-level processes, including specific actions such as judgments of learning, taking notes, and goal setting. These micro-level processes were further grouped conceptually into five macro-level categories: planning, monitoring, strategy use, task
difficulty and demands, and motivation (Greene & Azevedo, 2009, Greene et al., 2010). These macro-level categories are consistent with the processes described by the SRL models of Winne and Hadwin (1998), Pintrich (2000), and Zimmerman (2000). By using TAPs, Azevedo, Greene and colleagues showed that learners using certain specific SRL processes were better able to obtain conceptual understanding than learners who did not use specific SRL processes, or used them less frequently. For example, Greene and Azevedo (2007a) explored differences in the use of micro-level SRL processes between learners who improved their conceptual understanding and learners who failed to improve their conceptual understanding. They found that there were specific micro-level SRL processes, such as making inferences, stating a FOK, and coordinating information sources that were used more frequently by students who reached a conceptual understanding. According to this study, students who did not reach a conceptual understanding used less effective processes, such as controlling the context, more frequently.

Azevedo and his colleagues’ think aloud protocol also allows researchers to investigate how learners’ characteristics affect their use of SRL during learning. For example, prior domain knowledge is a learner characteristic that has been investigated in several studies (e.g., Moos & Azevedo, 2008). In their study, Moos and Azevedo found that learners with high domain knowledge used more planning (i.e., activating prior knowledge and recycling goal in working memory) and monitoring (i.e., evaluating content and feeling of knowing) SRL processes than those with low prior domain knowledge; learners with low prior knowledge domain tended to use more of just a few selected strategies (i.e., note taking, summarizing, and memorizing) during learning. These findings support Winne and Hadwin’s
(1998) claim that monitoring and control interact with learners characteristics, including prior knowledge, to affect learning.

Recent research approaches have introduced valence to SRL TAP data (e.g., Greene et al., 2010). Valence is defined as a negative or positive value assigned to individual micro-level SRL processes (Azevedo et al., 2010). For example, certain metacognitive monitoring and regulatory processes such as JOL can be coded with valence. When a learner states “I do not understand this paragraph,” researchers could code this as negative JOL; whereas when the learner states “I do understand this paragraph” researchers could code this as positive JOL. The addition of valence can allow researchers to examine the micro-level feedback loops between metacognitive monitoring and control. Winne (2001) has suggested that as long as self-regulating learners are able to make accurate subjective judgments about their cognitive processes, they should be able to choose appropriate learning strategies as they metacognitively control their learning. According to this reasoning, how people regulate and control their learning strategies is entirely a function of the quality of their metacognitive judgments. For example, when learners indicate that they do not understand the text they have just read (i.e., negative JOL), it is expected that they would deploy a different strategy than the one they had been using such as knowledge elaboration, because it would be adaptive for learners to change strategies to something they think might be more effective than the one they had been using before the negative JOL. Empirical work is needed to support the claim that metacognitive control is enacted based upon the quality of metacognitive monitoring (Azevedo et al., 2010) and that this metacognitive behavior predicts academic performance (Winne, 2004).
Current Study

In this study, I investigated the relationship between metacognitive monitoring and metacognitive control, two key components of SRL, and their effect upon learning. The aim was to provide further information about the role of metacognitive behavior in SRL when learning with HLEs. Studies have shown that HLEs are being used more often, and learners who do not self-regulate their learning effectively will not learn as well from HLEs as learners who do self-regulate their learning (Greene & Azevedo, 2007a). Therefore, it is important to understand how SRL functions in a HLE.

For this investigation, I used negative JOL as the key metacognitive monitoring process, and looked for strategy changes that followed a negative JOL as a way of capturing metacognitive control. A strategy change after a negative JOL was a sign of adaptive metacognitive behavior. If there is no strategy change following a negative JOL, I counted it as a static metacognitive behavior. Prior knowledge was included as a covariate because research has shown that it is a strong predictor of conceptual understanding (Azevedo & Cromley, 2004; Azevedo et al., 2005, 2008; Greene & Azevedo, 2007b; Greene, Moos, Azevedo, & Winters, 2008).

Research Question

My research questions were:

1. Does the frequency of negative JOL followed by a change in strategy use (i.e., adaptive metacognitive behavior) predict posttest conceptual understanding of a complex science topic with HLE, after controlling for pretest prior knowledge?
2. Does the frequency of negative JOL not followed by a change in strategy use (i.e., static metacognitive behavior) predict posttest conceptual understanding of a complex science topic with HLE, after controlling for pretest prior knowledge?
CHAPTER 3

METHOD

Participants

For this study, I conducted a secondary analysis of data collected for another study (Greene et al., 2010). This prior study was conducted during the 2007-2008 school year at a large public University in the Southeast. For this study, 170 undergraduate students were recruited in their education classes. Students received extra credit in the course in which they were recruited in exchange for their participation. Participants consisted of 103 females and 67 males with a mean age 19.9 years (SD=2.14 years). For my thesis research, I only included the 81 participants who used negative JOL at least once during the learning session, to capture the metacognitive behavior in which metacognitive control is enacted by metacognitive monitoring. 49 of the included participants were female and 32 of them were male with a mean age 19.7 years (SD=1.33 years).

Measures

For this study all participants completed a consent form, demographic questionnaire, and a paper-and-pencil pretest and posttest. The demographic questionnaire included basic information such as gender, age, academic major, and grade point average. The questionnaire also included a section related to their knowledge about health and biology, including coursework and work experience. The pretest and posttest were used to measure participants’
declarative and conceptual knowledge about the circulatory system. These tests have been successfully used in previous studies (Azevedo, 2005; Azevedo, Guthrie et al., 2004). The pretest and posttest were exactly the same. The tests consisted of three sections: matching, labeling, and an open-ended essay prompt. On the matching section, participants attempted to identify the definitions of 13 terms by matching the term with the appropriate definition. On the labeling section, participants were asked to label 14 components of the human heart. The matching and labeling sections measured only declarative knowledge about the circulatory system. For the final section of the test, an open-ended essay prompt was used. The prompt was: “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.” This essay was designed to measure participants’ conceptual understanding of the circulatory system.

Researchers employed SEM to test the reliability and validity of scores for both the pretest and posttest (Greene et al., 2010). Pretest internal consistency reliability, across all three measures, was 0.79 and posttest internal consistency reliability was 0.81. Also, in a previous study, Azevedo and colleagues used factor analysis to confirm support for the construct validity of these measures (Azevedo et al. 2007). For this study I used only the data from the essays (see Appendix B), because I was most interested in how metacognitive behavior related to deep conceptual understanding, which was only captured by the essays.

**Hypermedia Learning Environment (HLE)**

A commercially available HLE called Microsoft Encarta (2007) was used in this study. Students were asked to learn about the circulatory system by using this HLE. Researchers identified the three most useful articles in Encarta (i.e., the heart, blood, and
circulatory system) for students to achieve this learning task. These three articles 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 in Encarta; but they were asked not to access the internet or use Encarta’s dictionary function.

Procedure

The researchers followed a procedure similar to that used by Azevedo and colleagues (Azevedo & Cromley, 2004; Azevedo, Guthrie et. al., 2004; Greene & Azevedo, 2007a). Sessions were conducted with only one participant and one researcher present in the lab. First, researchers informed the participants that the entire study would take approximately 90 minutes and that they could leave the experiment at any time without penalty. Once participants agreed to participate, they read and signed the consent form. Next, they were asked to complete the demographic questionnaire.

Then, the researcher gave participants instructions on how to complete the pretest. Participants were given 20 minutes to complete the pretest. They were also asked to inform the researcher if they finished earlier than the time given. The researcher introduced participants to each section of the test and read aloud the essay prompt. The researcher instructed participants to complete the test sections in order without flipping back and forth between the sections. The researcher stayed in the room and answered any questions not related to the content of the test.

After finishing the pretest, the researcher introduced participants to the HLE with the three primary articles: heart, blood, and circulatory system. Participants were also instructed
on how to control Encarta, including how to access and control the heart video, how to utilize Encarta’s search functions, how to navigate within Encarta using the forward and back buttons, and how to use highlighted hyperlinks within articles to get more information on a topic or to move between articles. Next, the researcher introduced the think-aloud protocol. The participants were told to verbalize everything they were thinking, including reading aloud, stating any actions they were taking in the HLE (e.g., clicking on the heart article), and stating when they took notes. After this, the researcher let participants practice thinking-aloud with an article unrelated to the circulatory system for one to two minutes. The researcher answered any questions that participants had about the process.

After this practice session, the researcher introduced participants to the learning task. The researcher read the learning task to participants and provided a written copy of the learning task that 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.
Once the final questions were answered, the 30 minute session began. During this 30-minute session, participants were both audio and video taped. The video camera captured only the screen, desk area, and the side of participants’ head. The video camera was positioned to allow researchers to determine where participants were looking while conducting the learning task. It did not show participants’ faces. Participants were allowed to take notes, and 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. The researcher prompted the participant by saying “please say out loud what you are thinking” if he or she stopped thinking aloud. At the end of the 30 minutes, all recording was stopped, the HLE 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 20 minutes to complete the post-test, which was the same as the pre-test. Participants were told that they should inform the researcher if they finished early. When they completed the posttest their elapsed time was recorded. All participants were asked not to share the details with any of other participants.

**Scoring Knowledge Measures**

To score the knowledge measures (i.e., pretest and posttest), researchers used a method developed by Azevedo and colleagues (Azevedo, 2005). This method has been used in numerous studies (Azevedo & Cromley, 2004; Azevedo, Cromley et. al., 2004; Azevedo, Guthrie et al., 2004; Azevedo et al., 2005, 2007, 2008; Greene et. al., 2008). Researchers graded all pretests and posttests separately for each of the three sections.

Researchers scored the first two sections, matching and labeling, for accuracy. They assigned one point for a correct answer and zero points for a wrong answer. Scores on these
sections were not used for this study. The mental-model essays were scored individually by two researchers. A rubric used to score this part was also developed by Azevedo and colleagues (Azevedo, 2005) and has been used in previous studies (Azevedo & Cromley, 2004; Azevedo, Cromley et al., 2004; Azevedo, Guthrie et. al., 2004; Azevedo et al., 2005, 2007, 2008; Greene et. al., 2008, 2010). This rubric (see Appendix C) outlines 12 separate mental models that represent various levels of understanding from no understanding to a complete understanding. The key distinctions are an understanding that the lungs are a part of the circulatory system, and that the circulatory system involves a double loop of blood flow including the lungs and the body.

Therefore, an increase from model 1 to 6 indicates only a quantitative change in students’ understanding of the circulatory system, not a qualitative change. However, an increase from model 6 to 7 indicates a qualitative change in students’ understanding. For example, students that have a mental model of 1 to 6 recognize in some degree that blood circulates, but fail to note the significance of the lungs to the circulatory system. Researchers assign a mental model of seven or higher when a participant states in his or her essay that the lungs are a part of the circulatory system. The next qualitative shift 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.

Two of the researchers individually graded each essay by assigning one of the 12 mental model values. The inter-rater agreement for this process was .994 with agreement on 334/336 essays. The disagreements on the two essays were resolved by the primary investigator. The inter-rater agreement scores for previous studies ranged between .90 and .96 (Azevedo et al., 2005; Azevedo et al., 2007; Azevedo, Cromley et. al., 2004).
Transcribing and Coding of SRL Processing

In order to capture participants’ SRL processing, audio tapes of participants’ TAPs were transcribed by graduate and undergraduate lab members. Parts that were read directly from Encarta were transcribed as well. These parts were marked by italics to separate them from the participants’ codeable thoughts. The video recording was used to verify the transcriptions. Therefore, participants whose video recordings were lost were excluded from the analysis. 11 participants were excluded from this part of the study because of video loss.

Once transcribed, each transcription was coded using an SRL coding scheme (see Appendix D). This coding scheme was similar to a coding scheme developed by Azevedo and colleagues (Azevedo et. al, 2005; Azevedo & Cromley, 2004). This coding scheme included 31 micro-level SRL processes used by learners to regulate their learning of complex science topics within a HLE. These micro-level processes were further grouped into five macro-level processes: Planning, monitoring, strategy use, task difficulty and demands, and interest.

All transcripts were coded by the primary investigator and a team of graduate students. The graduate students received individualized training from the primary investigator before they began the actual coding for the study. They coded each of participants’ think-aloud protocols by labeling each codeable segment with the appropriate micro-level SRL process. To qualify as a codeable segment, a word or group of words had to represent one of the micro-level SRL processes. The segments which did not represent any of those SRL processes were labeled as “not codeable” and they were not included in the analysis, unless the words were being re-read. Words read directly from the Encarta were not coded. Two researchers coded each transcript individually by using both transcription and
video recording to ensure accuracy. Then they came together to compare their coding. Differences were discussed and resolved by the two coders. Statistical calculations of interrater agreement were not reported for this study because every segment was coded independently by two researchers. The values of inter-rater agreement for similar previous studies were between .97 and .98 (Azevedo et. al., 2005; Azevedo et. al., 2007; Azevedo, Cromley et. al., 2004)

**Data Preparation**

Only participants from the original study who used negative JOL were included in this secondary analysis. Negative JOL was selected as the key monitoring process in this study because it provided an opportunity to trace metacognitive behavior using SRL TAP data. Participants who did not enact a negative JOL were excluded from the study. Another option would have been to include the latter participants in the analysis by assigning them a score of zero. Zero would mean that those participants did not enact metacognitive behavior. I chose not to include participants who did not enact any negative JOL because it could be the case that those people simply understood everything, and did not need to make a negative judgment of their learning. In this case, assigning them “zero” would have caused a misinterpretation of the frequency data on the metacognitive behavior.

I examined participants’ behavior before and after the use of negative JOL, to determine whether metacognitive control was enacted. I looked at the strategy used before a negative JOL, and whether the participant changed his or her strategy after the negative JOL. If a strategy change occurred, I counted that as an instance of metacognitive control and coded it as an adaptive metacognitive behavior. I also defined another code, static metacognitive behavior, for instances where participants produced a negative JOL but did not
change their strategy after the negative JOL. Thus, I created two variables: adaptive metacognitive behavior and static metacognitive behavior. Of the 170 participants, 82 produced at least one negative JOL, but one participant was excluded from the analysis because he or she did not have pretest and posttest results. Therefore, 81 participants were included in the analysis.

**Data Analysis**

My intention was to examine whether the frequency and kind of metacognitive behavior were related to learning performance. In this study, therefore, I looked at whether the frequency of adaptive metacognitive behavior predicted posttest conceptual knowledge, after controlling for a pretest measure of knowledge. I also included the static metacognitive behavior variable to the analysis to differentiate the effects of adaptive and static metacognitive behaviors on learning. Because the research has shown that prior knowledge can affect both SRL behavior and academic performance (Greene et al., 2010), I included participants’ prior knowledge as a covariate in this analysis. Pre-test mental model scores were used as participants’ prior knowledge indicator. I used SPSS 17.0 to conduct the analysis.
I examined the relationship between the frequency of learners’ adaptive and static metacognitive behavior and their conceptual understanding, controlling for prior knowledge. My first research question was: Does the frequency of negative JOL followed by a change in strategy use (i.e., adaptive metacognitive behavior) predict posttest conceptual understanding of a complex science topic with HLE, above and beyond prior knowledge? My second research question was: Does the frequency of negative JOL not followed by a change in strategy use (i.e., static metacognitive behavior) would be negatively related to posttest conceptual understanding of a complex science topic with HLE, above and beyond prior knowledge?

**Descriptive Statistics**

In this study, conceptual understanding was operationalized as posttest mental model scores and prior knowledge was operationalized as pretest mental model scores. I treated the mental model scores as continuous variables. Adaptive metacognitive behavior variable represented the number of times that participants changed their strategy after a negative JOL. Static metacognitive behavior variable represented the number of times that participants did not change the strategy used after a negative JOL. Table 1 shows descriptive statistics for all variables.
Examination of the descriptive statistics shows that, on average, participants’ mean and median mental model scores increased from pretest to posttest. Thus, descriptive data show that participants, on average, did learn from pretest to posttest. The descriptive statistics for the metacognitive behavior variables reveal that, on average, participants employed more adaptive metacognitive behavior than static metacognitive behavior. Finally, skewness and kurtosis statistics indicate that the variables were approximately normally distributed.

The results of the correlations are shown in the correlation matrix on next page.
Before the regression analysis, outliers were examined for each predictor. Results of this procedure revealed no extreme values. Then, the examination continued with matrix scatterplots, which showed a somewhat linear relationship between all independent variables and the dependent variable (see Appendix E). Next, a series of multiple regression analyses were conducted in which the independent variables were entered in a sequence. The first model included prior knowledge (i.e., pretest mental model score) as a control variable. In the second step, adaptive metacognitive behavior and static metacognitive behavior variables were added as a block. The model including step one, \( F(1, 79) = 28.50, p < .000 \), and the model including step 2, \( F(3, 77) = 19.04, p < .001 \), were both statistically significant. Table 3 summarizes the analysis.

### Multiple Regression Analysis

<table>
<thead>
<tr>
<th>Measure</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mental Model posttest</td>
<td>—</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Mental model pretest</td>
<td>.515**</td>
<td>—</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Adaptive metacognitive behavior</td>
<td>.359**</td>
<td>.237*</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>4. Static metacognitive behavior</td>
<td>-.222*</td>
<td>.177</td>
<td>.043</td>
<td>—</td>
</tr>
</tbody>
</table>

*\( p < .05 \), **\( p < .01 \)
Table 3

Hierarchical Multiple Regression Analyses Predicting Learning Outcome From Adaptive and Static Metacognitive Behaviors After Controlling for Prior Knowledge

<table>
<thead>
<tr>
<th>Predictor</th>
<th>$\Delta R^2$</th>
<th>b</th>
<th>SE b</th>
<th>$\beta$</th>
<th>df</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td>.27**</td>
<td>.60</td>
<td>.11</td>
<td>.51**</td>
<td></td>
<td>(1, 79) 28.50**</td>
</tr>
<tr>
<td>Pretest mental model score</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2</td>
<td>.16**</td>
<td>.46</td>
<td>.16</td>
<td>.25*</td>
<td></td>
<td>(2, 77) 10.79**</td>
</tr>
<tr>
<td>Adaptive metacognitive behavior</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Static metacognitive behavior</td>
<td>- .93</td>
<td>.25</td>
<td></td>
<td>-.32**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total $R^2$</td>
<td>.43**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(3, 77) 19.04**</td>
</tr>
<tr>
<td>n</td>
<td>81</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$p<.01$, $**p<.001$

43% of variance in participants’ posttest mental model score was explained by the full regression model. Furthermore, there was a statistically significant positive relationship between posttest mental model score and pretest mental model score; as well as between posttest mental model score and adaptive metacognitive behavior. There was a statistically significant, negative relationship between posttest mental model score and static metacognitive behavior. Finally, the residual statistics had a minimum value of -2.342 and a maximum value of 2.081, indicating that the assumption of normality was not violated. Mahalanobis’ distance (13.818) indicated that there was no outlier significantly separated from the rest of the data. Although the maximum value of Cook’s distance (.096) appeared a
bit over the threshold (.0519), the difference was not large enough to influence the results of the regression analysis. Therefore I decided not to exclude any participant from the data.

Summary

The aim of this study was to reveal the relationship between metacognitive behavior and conceptual understanding, controlling prior knowledge. Based on a multiple linear regression analysis, it was found that both adaptive and static metacognitive behavior contributed to the prediction of conceptual understanding, above and beyond the effect of prior knowledge. With a model including prior knowledge and metacognitive behavior, 43% of the variation in participants’ conceptual understanding was explained. This result provided support for SRL theory in that adaptive metacognitive behavior was associated with higher posttest scores, and static metacognitive behavior was associated with lower scores, controlling for prior knowledge.
CHAPTER 5
DISCUSSION

In this study, I investigated the relationship between metacognitive monitoring and metacognitive control, two key components of SRL, and their “effects” upon learning. Specifically, I examined the relationship between the frequency of learners’ use of negative JOL followed by a change in strategy use and conceptual understanding. According to Winne and Hadwin’s (1998) SRL theory, metacognition includes two components: monitoring and control. Monitoring is an evaluation process and it produces a judgment of learning; control is a complementary process by which learners adjust how they are engaging learning. For example, when learners decide that they do not understand what was just read (i.e., judgment of learning), they should enact another learning strategy such as note taking or drawing (i.e., control). In the data, I looked for negative JOLs and then traced whether strategy change enacted after negative JOLs. If a negative JOL was followed by a strategy change, I called it a adaptive metacognitive behavior; if not, then I called it a static metacognitive behavior. In the data, conceptual understanding was represented by posttest mental model score and prior knowledge was represented by pretest mental model. My research question one was: Does the frequency of negative JOL with a subsequent change in strategy use predict posttest conceptual understanding of a complex science topic with HLE, after controlling the pretest prior knowledge? My research question two was: Does the
frequency of negative JOL without a subsequent change in strategy use predict posttest conceptual understanding of a complex science topic with HLE, after controlling the pretest prior knowledge?

Azevedo and colleagues’ (Azevedo, 2005; Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie et.al., 2004; Greene & Azevedo, 2007a) SRL TAP coding scheme was used to capture the self-regulated learning processes that students used while learning about the circulatory system in a hypermedia environment. For the purposes of this study, I recoded the data for adaptive metacognitive behavior and static metacognitive behavior to generate a frequency for each of the metacognitive behaviors.

Multiple linear regression analysis produced a statistically significant result that suggested that frequencies of both adaptive and static metacognitive behavior predicted posttest conceptual understanding of a complex science topic with HLE, after controlling for pretest prior knowledge. According to the results, whereas adaptive metacognitive behavior positively related to learning, static metacognitive behavior negatively related to it. The findings have both theoretical and methodological implications.

**Implications**

First, findings from this study provided evidence supporting Winne and Hadwin’s (1998) claim that metacognition is a key predictor of learning. In their SRL model, metacognitive monitoring and metacognitive control are viewed as the pivots on which SRL turns. Metacognitive monitoring yields subjective judgments of learning and these judgments should be used to guide adaptive strategy change (i.e., metacognitive control). No prior research has really examined specific instances of metacognitive behavior, and whether the quality of metacognitive behavior predicts learning. The results of my study align with the
theory, showing that adaptive metacognitive behavior positively relates to learning, whereas static metacognitive behavior negatively relates to learning. Therefore, the findings provide valuable implications for the benefits of using negative JOL as a guide to control behavior (i.e., strategy change) when learning with HLEs. For example, it would be helpful for users’ learning if HLEs could be designed with specific prompts that can lead users to engage in adaptive metacognitive behavior, rather than static metacognitive behavior. For example, an HLE can frequently ask students whether they have learned what they have just studied. If the answer is no, then the HLE can prompt the student to change the strategy just used by suggesting alternative strategies to choose.

Although in this study JOL was a key monitoring process for metacognitive behavior that was associated with the learning outcome, previous studies have produced mixed results regarding JOL’s relationship to learning. For example, Greene and Azevedo (2007) did not find a significant relationship between mental model posttest score and the frequency of use of JOL but they did find a relationship between posttest score and the frequency of use of another monitoring process, feeling of knowing (FOK). In their study, they used Azevedo and colleagues’ SRL TAP coding scheme however they did not use valance to differentiate negative and positive JOL. The current study showed that negative JOL predicted learning differently depending on whether it was followed or not followed by a change in strategy used before the negative JOL. Negative JOL with a change in strategy positively related to learning, whereas negative JOL without strategy change negatively relates to learning. In Azevedo and Greene’s study, it might be the case that most of the negative JOLs were not followed by strategy change (i.e., static metacognitive behavior). In this situation, combining the frequencies of negative and positive JOLs would diminish the positive effect of JOL.
(both negative and positive) on learning. Therefore, it is critical that researchers include valence when investigating JOL’s role in learning. Also, researchers should look at metacognitive behavior (i.e., monitoring and control), not just either monitoring or control on its own. To be able to trace metacognitive behavior in SRL, the SRL TAP method and coding scheme with valence play critical roles because valence provides an opportunity to catch the interplay between monitoring and control.

**Limitations**

There are some limitations regarding the design of the original study (Greene et al., 2010a). First, the original study was a non-experimental, correlational study. Therefore, casual inferences about the relationship between metacognitive behavior and learning cannot be made. The study used a science topic, the circulatory system, and the HLE, Microsoft’s Encarta. Therefore, findings for this study are specific to this HLE and the circulatory system. The sample for this study consisted of undergraduate students at a single university in the South. This limits the generalizability of the findings.

Another limitation concerns the coding for metacognitive behavior. In this study, I used the terms adaptive and static to differentiate the quality of metacognitive behavior that participants enacted. However, these terms are most likely oversimplifications of a complex interaction between individual characteristics, CBLE, academic content, and learning. What is "adaptive" in one context may not be adaptive in another context, or with a different person. Further, in the future, it might be helpful to be more discerning about which strategies are classified as helpful or not. In this study, I only looked for a strategy change after a negative JOL, without considering whether the new strategy was helpful or not. Such an approach would first require a qualitative study about which strategies are more helpful
than others. This approach, then, might influence the coding of adaptive/static metacognitive behavior.

**Future directions**

A qualitative study could be conducted to explore participants’ strategy use and determine why participants engaged in static metacognitive behavior. One potential reason may be that participants’ knowledge of strategies is limited. Or, perhaps participants know the strategies, but do not know how and when to use them. Determining how participants employ strategies differently and how this variance in strategy use affects learning would have critical implications for educators when deciding whether to focus on teaching strategies or teaching how and when to use strategies. For example, such a study could reveal that participants know sufficient strategies, however they do not know how and when to use them. In this case, the aim in education should be not only to teach strategies to students, but also to teach them how and when to use those strategies.

Although this study revealed statistically significant relationships between metacognitive behavior and learning, an experimental study would allow for a causal interpretation. For such a study, two groups, one with instructions on how to enact adaptive metacognitive behavior and one with no instruction, could be compared to see whether there were differences in their learning outcomes. Also, collecting SRL TAP data would be critical for this study to determine whether the intervention was effective in terms of promoting adaptive metacognitive behavior.

This study provided support for the efficacy of Azevedo and colleagues’ SRL coding scheme. I believe that this coding scheme can also be improved by including other micro-level processes. For example, “time management”, or “study time allocation”, strategy could
be added to the coding scheme to capture whether students manage their time by allocating study time for each sub-topic. Similar strategies have been used in previous metacognition studies (Son & Metcalfe, 2000; Thiede, Anderson & Therriault, 2003).

**Conclusions**

Findings supported SRL theory in that participants who employed adaptive metacognitive behavior tended to have higher posttest mental model scores, and participants who employed static metacognitive behavior tended to have lower posttest mental model scores. This supports Winne and Hadwin’s (1998) claim that metacognitive monitoring and metacognitive control enacted by metacognitive monitoring is a key in SRL. Therefore, it seems critical to improve students’ ability to enact adaptive metacognitive behavior when learning with HLEs.
Appendix A: Winne and Hadwin (1998) SRL model

Adapted from Winne & Hadwin's (1998) Model of Self-Regulated Learning
Appendix B: Conceptual Knowledge Essay

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.

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Please use the back of this sheet if you need more space....
Appendix C: Mental Models

Necessary Features for Each Type of Mental Model (based on Azevedo et al., 2007)

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

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
   - describes “purpose” – oxygen/nutrient transport
   - mentions one of the following: electrical system, transport functions of blood, details of blood cells

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: 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)

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

<table>
<thead>
<tr>
<th>Macro-Level Process: Monitoring</th>
<th>Micro-Level Processes</th>
<th>Description</th>
<th>Student Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content Evaluation (Plus and Minus) (CE+/-)</td>
<td>Monitoring content relative to goals. Learner states content is or is not useful toward reaching the goal.</td>
<td>&quot;I'm reading through the info but it's not specific enough for what I'm looking for&quot;</td>
<td></td>
</tr>
<tr>
<td>Expectation of Adequacy of Content (Plus and Minus) (EAC+/-)</td>
<td>Expecting that a certain type of representation will prove either adequate or inadequate given the current goal</td>
<td>&quot;...the video will probably give me the info I need to answer this question&quot; or &quot;I don’t think this section on blood pressure will answer my question&quot;</td>
<td></td>
</tr>
<tr>
<td>Feeling of Knowing (Plus and Minus) (FOK+/-)</td>
<td>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</td>
<td>&quot;… I recognize that from the pretest…” or &quot;atherosclerosis – I never heard that word before.”</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Micro-Level Processes</th>
<th>Description</th>
<th>Student Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Video (CV)</td>
<td>Using pause, start, rewind, or other controls in the digital animation</td>
<td>Clicking pause during the video</td>
</tr>
<tr>
<td>Coordinating Informational Sources (COIS)</td>
<td>Coordinating multiple representations, e.g., drawing and notes.</td>
<td>“I’m going to put that [text] with the diagram”</td>
</tr>
<tr>
<td>Draw (DRAW)</td>
<td>Making a drawing or diagram to assist in learning</td>
<td>“…I’m trying to imitate the diagram as best as possible”</td>
</tr>
<tr>
<td>Inferences (INF)</td>
<td>Making inferences based on what was read, seen, or heard in the hypermedia environment</td>
<td>…[Learner sees the diagram of the heart] and states “so the blood….through the …then goes from the atrium to the ventricle… and then…”</td>
</tr>
<tr>
<td>Knowledge Elaboration (KE)</td>
<td>Elaborating on what was just read, seen, or heard with prior knowledge</td>
<td>[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”</td>
</tr>
<tr>
<td>Memorization (MEM)</td>
<td>Learner tries to memorize text, diagram, etc.</td>
<td>“I’m going to try to memorize this picture”</td>
</tr>
<tr>
<td>Prior Knowledge Activation (PKA)</td>
<td>Searching memory for relevant prior knowledge either before beginning performance of a task or during task performance</td>
<td>“It's hard for me to understand, but I vaguely remember learning about the role of blood in high school”</td>
</tr>
<tr>
<td>Read Notes (RN)</td>
<td>Reviewing learner’s notes.</td>
<td>“Carry blood away. Arteries—away.”</td>
</tr>
<tr>
<td>Re-reading (RR)</td>
<td>Re-reading or revisiting a section of the hypermedia environment</td>
<td>“I’m reading this again.”</td>
</tr>
<tr>
<td>Search (SEARCH)</td>
<td>Searching the hypermedia environment with or without the Encarta search feature</td>
<td>“I’m going to type blood pressure in the search box”</td>
</tr>
<tr>
<td>Selecting a New Informational Source (SNIS)</td>
<td>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.</td>
<td>[Learner reads about location valves] then switches to watching the video to see their location</td>
</tr>
<tr>
<td>Summarization (SUM)</td>
<td>Summarizing what was just read, inspected, or heard in the hypermedia environment</td>
<td>“This says that white blood cells are involved in destroying foreign bodies”</td>
</tr>
<tr>
<td>Taking Notes (TN)</td>
<td>Copying text from the hypermedia environment</td>
<td>“I’m going to write that under heart”</td>
</tr>
</tbody>
</table>

**Macro-Level Process: Task Difficulty and Demands**

<table>
<thead>
<tr>
<th>Micro-Level Processes</th>
<th>Description</th>
<th>Student Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Help Seeking Behavior (HSB)</td>
<td>Learner seeks assistance regarding either the adequateness of their answer or their instructional behavior</td>
<td>“Do you want me to give you a more detailed answer?”</td>
</tr>
</tbody>
</table>

**Macro-Level Process: Interest**

<table>
<thead>
<tr>
<th>Micro-Level Processes</th>
<th>Description</th>
<th>Student Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest Statement (Plus and Minus) (INT+/−)</td>
<td>Learner has a certain level of interest in the task or in the content domain of the task</td>
<td>“Interesting”, “This stuff is interesting”</td>
</tr>
</tbody>
</table>
### Appendix E: Matrix Scatterplots

![Matrix Scatterplots Diagram](image-url)

*Legend:*
- `mmp`: Metacog
- `mmp`: Metacog
- `mmp`: Metacog
- `mmp`: Metacog

*Notes:*
- The scatterplot matrix shows the relationships between different cognitive states and their performance metrics.
- Each cell represents a pairwise comparison between two variables, with data points indicating the strength and nature of the relationship.
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