Examining the Complex Nature of Emotion, Metacognition, and Study-Time in Multimedia Learning

Amber Dawn Chauncey

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EXAMINING THE COMPLEX NATURE OF EMOTION, METACOGNITION AND STUDY-TIME IN MULTIMEDIA LEARNING

by

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A Thesis

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“Don’t be ashamed to need help. Like a soldier storming a wall, you have a mission to accomplish. And if you have been wounded and you need a comrade to pull you up? So what?

-Marcus Aurelius

The realization of this thesis has been a challenge, an adventure, a sweet torment, and a sweeter victory. Most of all, it has been a learning experience. Looking back on the obstacles I overcame to achieve this success, I can say with certainty that I owe the sincerest gratitude to the people who got me here. I doubt that my writing is sufficient enough to express my appreciation for these people, but with the humblest heart I shall try.

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Abstract

Learning with multimedia is challenging and often requires learners to regulate cognitive, metacognitive, and affective processes in order achieve optimal learning. The purpose of the current study was to examine the effect of induced emotional states on learners’ metacognitive monitoring and control, and learning performance in a self-paced multimedia learning environment. A within-subjects design and a false-biofeedback paradigm were used to induce various emotional states in 50 undergraduate participants while they answered both text-based and inference questions about the human circulatory system. Across 24 trials, participants were presented with accelerated, baseline, and no heart rates (control) and were asked to make various metacognitive judgments (Ease of learning, immediate judgments of learning, and retrospective confidence judgments) and answer questions about the circulatory system. Results indicated that, overall, participants made significantly more confident metacognitive judgments and achieved significantly higher learning performance when they heard an accelerated heart rate than when they heard a baseline or no heart rate.
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Introduction

The United States has a long history of lagging behind other developed nations in math and science learning. According to the National Science Teachers Association (NSTA), in 2008 U.S. students were being outscored in science by their peers in Finland, Canada, Estonia, Singapore, Japan, and Hungary, among others. Nearly 25% of 15 year olds in the U.S. did not demonstrate competency at the baseline level. The assessment for determining baseline competency requires that students possess scientific knowledge and use that knowledge to draw evidence-based conclusions, and to recognize that science is a form of human inquiry. It also requires that students maintain an awareness of how science shapes our intellectual and cultural environment, and demonstrate a willingness to engage in scientific issues. The NSTA claims that this trend in poor competency is due to the fact that science is not being emphasized enough in U.S. classrooms, and that educators need more resources to effectively teach science. Compared to other developed nations, the United States dropped from 14th in science in 2000 to 19th in 2003 and 21st in 2006. According to the Program for International Student Assessment (PISA, 2006) the U.S. will feel the effects of these trends through lower wages and reduced standard of living within 15 years.

Beginning in middle school and continuing through high school and beyond, students are faced with learning about conceptually-rich domains such as physics, ecology, chemistry, and biology. It is in these domains that adolescents and young adults in the U.S. show the greatest deficits compared to other developed countries. However, research has shown that students’ learning can improve through the deployment of key cognitive and metacognitive processes such as planning (i.e., setting sub-goals, time and effort planning), monitoring (i.e., content evaluation, monitoring progress towards goals, and making judgments about learning), and learning strategies (i.e., generating hypotheses, making inferences, and summarizing). (Azevedo,
2008; Dunlosky & Metcalfe, 2009; Graesser, Dunlosky, & Hacker, 2009; Pintrich, 2000; Winne & Hadwin, 1998, 2008; Zimmerman, 2000). These processes, also called self-regulated learning (SRL) processes, are based on the assumption that students actively monitor and control their learning (Azevedo & Witherspoon, 2009) to aid in deeper processing of the material.

A problem with this assumption is that conceptually-rich domains contain inherent anxiety-provoking factors such as environmental stressors (complexity or presentation style of the learning materials), uncertainty about how easily the material can be comprehended, and the fear of performing poorly on subsequent evaluations, which may interfere with students’ ability to effectively regulate their learning. While many conceptual models of SRL focus on students’ use of cognitive and metacognitive processes to regulate their learning (Azevedo, 2008; Dunlosky & Metcalfe, 2009; Dunlosky & Theide, 2004; Metcalfe, 2002; Zimmerman, 2000), the majority of these models do not explore the role of emotion in self-regulation. Beginning with Flavell (1979), the relationship between metacognition and learning has been the focus of stringent empirical research. In recent decades, a growing body of empirical research has demonstrated that learners’ emotional states have the potential to significantly impact their learning (Efklides, 2006; Efklides & Volet, 2005; Graesser et al., 2007; Pekrun, 2006; Pekrun, Goetz, Titz, & Perry, 2002). However, despite the rich history of emotion research and metacognition research in their respective domains, there is a tradition in the field of cognitive psychology for these two constructs to be examined independently of each other. In order to more fully understand the complex process of learning, metacognition and emotion should be studied together to determine how these processes influence one another, and how they coalesce to influence learning.
The current study attempted to resolve these issues by experimentally inducing emotional states through false biofeedback in order to understand how induced emotional states affect learners’ metacognitive judgments and allocation of study-time, and how these emotional states affect their performance on both text-based and inference questions related to the learning material. While there is no known method that can infallibly induce emotions in laboratory experiments, many researchers have employed a false-biofeedback paradigm (see Kirsch & Lynn, 1999). This non-invasive method involves instructing participants that a sensor will be used to collect and record their heart rate, and that they will hear a recording of their own heart rate through headphones. However, rather than hearing their own heartbeat, participants are presented with recordings of accelerated and baseline human heart rates. The purpose of this method is to cause participants to believe that they are experiencing physiological arousal when they hear an accelerated heart rate, and no arousal when they hear a baseline heart rate. Previous empirical research has suggested that individuals often evaluate their emotional state by their perceived level of physiological arousal (Cacioppo et al., 2000). Because of this method’s effectiveness in inducing subjective emotions and physiological responses, the proposed experiment used an accelerated heart rate, a baseline heart rate, and no heart-rate to induce emotional states in participants during a multimedia learning session.

Emotion in Learning

Learners often experience both positive and negative emotions during learning. Positive emotions associated with learning include interest, enthusiasm, motivation, curiosity, pride, and accomplishment. Negative emotions associated with learning include anxiety, apathy, resentment, helplessness, and frustration. These emotions can have serious negative consequences for students’ learning (Zeidner, 2007). Research has shown that emotions shape
learning at the very onset of the learning episode and therefore are strong contributors to actual learning.

Because emotions are often pervasive and inextricably bound to learning, extensive research is needed to determine how they unfold to facilitate or constrain learning. There is little existing theoretical or empirical research concerning the interaction of emotion, metacognition, study-time, and performance. Researchers need to understand: 1) how emotions affect metacognitive judgments; 2) how emotions affect learners’ allocation of study-time during learning; and 3) how emotions facilitate or constrain learning performance. This thesis has the potential to have a significant impact in the field of cognitive and educational psychology because it examined the interaction of these constructs during a multimedia learning session and explored how they affected learning performance.

The purpose of this thesis was to gain knowledge about the complex interaction of metacognitive and affective processes during learning, with the overarching goal of understanding how to help learners achieve effective self-regulation while learning with multimedia. Effective self-regulation, which necessitates learners to monitor, regulate, and control their cognition, metacognition, affect, and behavior (Azevedo, 2009), is a complex process that can be difficult for many learners. Multimedia learning can be even more challenging because it often requires the integration of multiple representations of the material (coordinating text and diagrams), and can often present a vast amount of material (Azevedo, 2008; Graesser, Chipman, Haynes, & Olney, 2005) The following section will discuss the importance of effective SRL during multimedia learning.
Self-Regulated Learning with Multimedia

Multimedia learning of complex science topics necessitates learners to effectively self-regulate their learning through the deployment of effective SRL processes related to planning, monitoring, and learning strategies (Azevedo, 2008; Graesser et al., 2007, Shapiro, 2008). Most SRL research focuses primarily on metacognitive judgments and control behaviors (see Dunlosky & Metcalfe, 2009 for a recent review). Metacognitive judgments are the result of monitoring processes that occur during learning as students assess their emerging understanding of the material and compare their knowledge state to their goal state (i.e., achieving mastery of the material). There are three metacognitive judgments that are most commonly examined in SRL research. These include Ease of Learning (EOL; judging the ease or difficulty with which the material can be learned), Judgments of Learning (JOL; assessing one’s emerging understanding of the material), and Retrospective Confidence Judgments (RCJ; assessing one’s confidence in the accuracy of responses to questions about the material). Control behaviors are actions taken by learners based on the results of metacognitive monitoring. The most frequently examined control behavior is study-time allocation (how much time the learner chooses to spend studying the material). Examining the relationship between metacognitive monitoring and control can lead to many answers about the ways in which learners self-regulate their learning. However, an equally important component that is not well conceptualized is the effect of emotion on metacognition. A few researchers have incorporated affect into their models and coding schemes, but none explicate the exact complex relationship between emotion, metacognitive monitoring, metacognitive control, and performance. According to Moreno and Mayer’s (2007) Cognitive-Affective Model of Learning (CAML, see Appendix A), emotions have the potential to impact learning from its inception (such as how much attention is paid to
the task and the learners’ perception of the task itself), in working memory (such as organizing incoming information), and during integration into long term memory (such as incorporating new knowledge with existing prior knowledge). This model has made a contribution to cognitive psychology by highlighting the relationship between emotion, cognition, and metacognition. However, it does very little to explain the precise nature of that relationship and how it can facilitate or constrain learning. The goal of this thesis was not to test the CAML. Rather, the goal was to attempt to answer questions which arise from this model in order to achieve a clearer conceptualization of emotion and SRL. Specifically, its main objective was to examine the relationship between emotion and metacognitive monitoring and control, since these processes are the central hubs of self-regulated learning (Winne, 2001; 2005; Winne & Hadwin, 2008; Zimmerman, 2006).

**Emotion and Self-Regulated Learning**

Presently there is little existing research that examines emotion and metacognition. However, there is evidence that negative emotional states can impair learners’ ability to accurately monitor and control their learning, while some positive emotional states can improve their ability to engage in these processes. A growing body of empirical research has demonstrated that positive affect can cause learners to be more interested in the task, to be more tenacious over time, to engage in deeper processing of the material, to more effectively monitor and control their learning, and to achieve higher learning performance on text based and inference questions about the topic (Miller, Green, Montavalo, Ravindran, & Nichols, 1996; Vensteenkiste, Simons, Lens, Soenens, & Matos, 2005). However, there is little existing research which attempts to understand the precise nature of how emotion and metacognition interact during multimedia learning. First, there is a need for a clear understanding of how emotions can
facilitate or impair learners’ metacognitive monitoring and control. The mood-as-information theory (see Schwarz & Clore, 2003) would predict that positive affect should cue learners that all is well, and allow learners to focus on the demands of the task rather than on their emotions. Increased attention to the task may lead to accurate metacognitive judgments and appropriate allocation of study-time, which may translate to increased learning performance. Negative emotions are expected to detract learners’ attention away from the task and onto their emotional states. This could impair learners’ ability to make accurate metacognitive judgments, and could cause them to allocate their study-time inappropriately, which could lead to decreased learning performance. However, it cannot be assumed that positive emotions will always improve metacognition and that negative emotions will always constrain it. Can feelings such as frustration or confusion improve learners’ ability to engage in accurate metacognitive judgments and control behaviors? Can pleasant feelings lead learners to focus their attention on their emotions rather than the learning task? These are questions that must be answered in order to gain a complete understanding of the complex processes that affect learning.

**Purpose of the Current Study**

This study attempted to identify the relationship between emotion and metacognition during learning by experimentally inducing emotional states and examining the differential ways in which metacognitive judgments and study-time allocation occur across different emotional states, and how these processes interact to affect learning performance. A within-subjects design was used to examine these processes in college students by experimentally inducing emotional states through false biofeedback.

All participants viewed 24 slides containing text and static diagrams about the circulatory system. For each trial, participants first previewed either a text based or inference question
related to the content they were about the study. They were then instructed to study the science content and provide three metacognitive judgments (EOL, JOL, and RCJ) at different time intervals, and to provide an answer to the question for each of the 24 trials. The goal of this procedure was to understand how metacognitive judgments, study-time allocation, and learning performance were affected by question type and induced emotional state (accelerated, baseline, or control). The specific research questions that were examined in this thesis were: 1) How does induced emotional state and question type affect participants’ metacognitive judgments during multimedia learning?, 2) How does induced emotional state and question type affect participants’ study-time allocation during multimedia learning, 3) How does induced emotional state and question type affect participants’ learning performance during multimedia learning?, and 4) How does induced emotional state and question type affect participants’ reported emotional states during multimedia learning?

**Literature Review**

This section begins by defining emotion, followed by a review of the empirical literature examining emotion in learning. Next, a brief theoretical background of SRL is presented. Specifically, this review focuses on metacognitive monitoring and metacognitive control, which are the two central hubs of SRL. Next, empirical research regarding three key metacognitive monitoring processes (EOL, JOL, RCJ) and one key control process (study-time allocation) will be presented. Fourth, the theoretical assumptions of the Cognitive-Affective Model of Learning (Moreno & Mayer, 2007) will be reviewed. Finally, a description of how the guiding theoretical principles and results from empirical research informed the design of the experimental procedure of the current experiment.
Defining Emotion

Since its emergence in the field of cognitive psychology, emotion and its many components have escaped any sort of empirically sound, consensual definition. Terms such as mood (Feldman, 1995; Lang, 1995), affect (Ketal, 1975), and feeling (Gross & Thompson, 2007) are used interchangeably to describe the fuzzy construct of emotion. Grappling with these various competing definitions is beyond the breadth of this thesis, so for these purposes, the definition proposed by Mauss, Cook, and Gross (2007) has been adopted. It states that emotions are multifaceted, contextual, and embodied phenomena that involve loosely coupled changes in the domains of subjective experience, behavior, and peripheral physiology (Mauss, et al., 2007).

Beginning with Darwin (1872) the adaptive function of emotional experience became an important topic of exploration in experimental science. A myriad of studies have found that emotions serve several essential adaptive functions. These can include initiating behavioral responses (Simon, 1967), influencing knowledge and goals (Ortony, Clore, & Collins, 1998; Russell, 2003) and enhancing memory for important events (Phelps, 2006). However, emotions are not always adaptive. They can often have negative results (Parrott, 1993). This occurs when they are the wrong type, when they occur at the wrong time, or when they occur at the wrong intensity level (Gross, 2002). For example, when learners experience anxiety related to learning about a complex science topic like biology, they may make low (i.e., unconfident) EOL judgments about the ease with which the material can be learned. Learners who can effectively regulate their emotions may use this metacognitive judgment (i.e., “this will be difficult to learn”) to make strategic decisions during learning (such as allocating more study-time to the material) which may facilitate learning. However, learners who cannot regulate their emotions may feel overwhelmed by the difficult material, and these feelings may detract attention from the
learning task and impair learning. Emotions are highly salient phenomena which are inextricably bound to learning (Graesser et al., 2007). Therefore, it is important to understand the ways in which emotion affects processing of the learning material and overall learning performance.

**Emotion and Learning Performance**

Emotions are powerful phenomena that have the potential to affect metacognitive monitoring and control during learning. The context of learning can be greatly altered by emotions because emotions influence attentional allocation, motivation, and inference strategies (Tooby & Cosmides, 2008). Learners’ emotions have the potential to alter their perceptions of the task (i.e., the perceived ease or difficulty of the task), their perceptions of themselves, (i.e., their perceived ability to handle the demands of the task), their metacognitive judgments about the task (i.e., how well they perceive to understand the content) and their perceptions of how much time should be allocated toward studying a given topic. Therefore, it is important for cognitive and educational psychologists to understand the complex effects of emotions on learning. The next section presents empirical research that examines these effects.

Researchers who examine the role of emotion during learning typically conduct their experiments in either laboratory environments (for example, using hypermedia, multimedia, or intelligent tutoring systems) or in classroom settings. While these methodologies have different implications in the fields of cognitive and educational psychology, the knowledge gained from both types of research is informative about the ways learners experience emotions during learning, and how learners’ emotional states impact other cognitive and metacognitive processes.

For example, D’Mello, Taylor, and Graesser (2007) used AutoTutor, an intelligent tutoring system, to examine affective trajectories during complex learning. The primary focus of the study was on the affective states of boredom, flow, confusion, frustration, delight, and
surprise. The authors found that when learners reported being in a negative emotional state (such as boredom) at one time interval they were likely to remain in a negative state in subsequent intervals. When learners reported a positive emotional state (such as delight) they tended to remain in this positive state, or transition to another positive state (such as flow). These results indicate that many affective states tend to be pervasive, meaning that once a learner “enters” one affective state he is likely to stay in that state.

This experiment is important because it was one of the first of its kind to examine emotion trajectories (transitions from one emotion to another) during learning. However, a primary limitation of this experiment is that they did not examine the effect of participants’ emotions on their learning performance. What are the consequences of dwelling on, for example, negative emotional states during learning? If negative emotional states do impair one’s ability to learn, can learners who have the ability to transition out of these emotional states avoid their deleterious effects?

In an attempt to answer some of these questions, Pekrun, Maier, and Elliot (2009) examined students’ emotions as predictors of learning performance on an in-class mid-term. In this classroom experiment, the authors found that positive and negative emotional states are not only pervasive, but they also have significantly different effects on learning. Results suggested that participants who reported positive emotions such as pride and hope achieved greater learning performance than participants who did not. Participants who reported negative emotions such as boredom, anger, anxiety, hopelessness, and shame achieved lower learning performance. Results also revealed that learners who reported high motivation were likely to experience positive emotions such as pride and hope, while learners who reported low motivation tended to experience negative emotions such as boredom and anger. Subsequently, high motivation and
positive emotions were found to lead to increased learning performance while low motivation and negative emotions were not. Similar results have been found by various other researchers (Pekrun et al., 2002; Schutz & Pekrun, 2007; Zeidner, 2007), which all demonstrate that negative emotional states can significantly impair learners’ ability to achieve optimal learning performance.

How might learners overcome the recusant effects of negative emotions on learning performance? A growing body of theoretical and empirical research suggests that learners need to be proficient at regulating the emotions they experience (Gross & Thomas, 2007; Schutz & Davis, 2001). Their claim is that learners should be equipped with strategies for down-regulating negative emotions and up-regulating or maintaining positive emotions. By using these strategies, learners may be able to avoid the negative effects that emotions can have on learning.

If emotion regulation is, in fact, a vital component of successful learning, why has this concept not been more closely examined in SRL research? The majority of empirical research examining SRL suggests the importance of regulating metacognitive monitoring and control processes during learning, but is limited in scope because it does not address: 1) the importance of regulating emotional processes during learning, and 2) what strategies learners should use to regulate the emotions they experience.

Before researchers can conceptualize the role of emotion regulation during learning, they must first understand how learners’ emotions affect other self-regulatory processes, such as metacognitive monitoring and control. For example, can emotional states affect learners’ accuracy of metacognitive judgments? Do learners allocate their study-time differently when they experience positive versus negative emotions? The current thesis attempted to address this issue by examining not only the effect of emotions on performance, but also their effect on
metacognitive monitoring and control processes which occur during learning. The goal of studying these complex processes together was to attempt to bridge the gap between emotion regulation literature and SRL literature, in order to offer a preliminary step toward integrating the role of emotion into existing models of SRL.

**Theoretical Background of Self-Regulated Learning.**

Self-regulated learning is an active and constructive process which involves students’ ability to build on their understanding of a topic or domain by using planning, monitoring, and learning strategies, and by regulating certain aspects of cognition, behavior, motivation, and affect in order to achieve some desired goal (Azevedo & Witherspoon, 2009; Boekaerts, Pintrich, & Zeidner, 2000; Koriat, Ma’ayan, & Nussinson, 2006; Pintrich, 2000; Zimmerman & Schunk, 2001). SRL can be further specified as a process which involves metacognitive monitoring and metacognitive control.

Learners use monitoring processes to assess the difficulty of the task, to evaluate their emerging understanding of the material, and to track their progression toward their goals. Learners should use feedback from these monitoring processes to control their learning by deciding how much time to spend studying a given topic. In a self-paced learning session where learners are able choose how much time to spend studying a topic, learners should spend more time studying topics that they perceive to have little existing knowledge about, or that they judge to be difficult to understand. Less time should be spent studying topics about which they already know, or which they judge to be easy to understand. Learners who are capable of engaging in accurate metacognitive monitoring processes, and using feedback from these processes to engage in appropriate control behaviors, are more likely to achieve deeper, more meaningful learning.
The next section will review empirical research which examines the complex processes of metacognitive monitoring and control during learning.

**Empirical Background of Self-Regulated Learning**

This section presents current empirical research related to metacognitive monitoring and metacognitive control. The following review will first discuss three key components of metacognitive monitoring that were used in the current study, including ease of learning, judgment of learning, and retrospective confidence judgments. It will then discuss study-time allocation, which is the most commonly examined component of metacognitive control.

**Ease of learning.** Ease of learning (EOL) judgments require students to preemptively determine how easily a given topic can be learned. EOL judgments occur in the prospective phase of learning and are assumed to help learners establish goals, sub-goals, and allocation of study-time, and can be used as a baseline for establishing future metacognitive judgments. For example, learners who judge that a topic will be difficult to learn might establish smaller, more achievable sub-goals rather than focusing on one distal goal that might be too difficult to achieve. They may also spend more time studying this difficult content. Despite the use of these strategies to improve their learning, these learners’ perceptions that the material is difficult to learn may influence their perception of their actual learning, resulting in less confident subsequent metacognitive judgments. Therefore, EOL judgments have the capacity to shape many aspects of learning at the very onset of the learning episode. Their ability to impact so many other cognitive and metacognitive processes that occur during learning necessitates researchers to examine how, when, and why they occur. The majority of existing research involving EOL judgments examines only how learners’ judgments affect their control behaviors.
during learning, or their overall learning performance. The next section will discuss some of these studies and how they relate to the current thesis.

Leonesio and Nelson (1990) conducted a study using paired associates to determine if learners could make accurate EOL, JOL, and FOK judgments. They examined participants’ accuracy of metacognitive judgments by comparing judgments to recall performance. They found that, overall, participants were very inaccurate at judging which items would be the easiest to learn (EOL) and which items were the most learned (JOL). That is, participants were unable to accurately monitor the difficulty of the task and their own ability to remember each pair. In this experiment, participants who perceived that a particular paired associate would be easy to remember may have spent less time committing that pair to memory. Spending an insufficient amount of time studying that pair may have impaired their ability to recall it later, which may have explained why their overall performance on the task to suffered.

While this experiment examined low-level learning of paired associates, these results can also be seen in learning of complex science. Learners who cannot accurately monitor: 1) how conceptually challenging a topic will be, and 2) how well they understand the material, are rendered incapable of appropriately allocating study-time to the topic and of making accurate subsequent metacognitive judgments. These findings highlight the need for examining how EOL judgments occur during learning and how they impact metacognitive monitoring, control, and learning performance.

The use of paired associates to examine learning is limited because the way students learn paired associates may be qualitatively different than the way they learn, for example, lengthy texts. To avoid this limitation, Theide, Anderson, and Therriault (2003) examined participants’ accuracy of metacognitive judgments while learning long texts such as biographies of historical
figures. For their experiment, participants first viewed titles of six paragraphs and were asked to provide an EOL judgments for each text. Participants then read each of the six texts and provided a JOL by indicating how well they believed they understood each text. Finally, all participants completed a post-test to assess their declarative knowledge about the texts.

The authors examined monitoring accuracy for all participants. Results suggested that participants’ judgments were significantly positively related to performance. For example, participants who made low EOL judgments (i.e., this will be difficult to learn) achieved low learning performance. This indicates that learners’ ability to accurately monitor their emerging understanding of a topic is directly correlated with performance.

These results, combined with those from Leonesio and Nelson’s experiment discussed above, are important to the design of the current study because they highlight the importance of learners’ accuracy of metacognitive judgments. Results from Leonesio and Nelson suggest that learners demonstrate a tendency to make inaccurate metacognitive judgments. However, results from Theide et al. indicate that metacognitive judgments are significantly correlated with learning performance. Therefore, it seems that learners who perceive that a given topic is difficult may achieve poor learning performance even if they did sufficiently learn the material. For researchers interested helping learners achieve optimal learning, this is an impasse that must be resolved.

Can prompting EOL judgments during a learning session help learners become more metacognitively aware of the ease or difficulty of the topic to be learned? If so, can increased metacognitive awareness at the onset of learning help learners make accurate subsequent metacognitive judgments and allocate sufficient time to studying the topic? Learners who identify a topic as difficult should spend more time studying the content than they would spend
studying topics they identify as easy. However, because empirical evidence indicates that learners have significant problems distinguishing which topics will be difficult to learn, it is important for researchers to delve deeper into the complex processes that occur after these metacognitive judgments are made. The purpose of including EOL judgments in the current thesis was two-fold. The first purpose was to determine if learners’ EOL judgments differ when they are asked to answer a text based versus an inference question. Presumably, because inference questions necessitate deeper processing of the material by requiring learners to bridge concepts found within two or more sentences within the text, learners who are metacognitively aware should make less confident EOL judgments for these questions. The second purpose was to examine how learners’ EOL judgments shaped their subsequent metacognitive judgments and their control behaviors throughout a multimedia learning session. Understanding these complex relationships is vital for improving learning research in both cognitive and educational psychology.

Despite the knowledge that EOL judgments are useful for helping learners better regulate their learning, few empirical studies have closely examined their role during learning of complex material. Other metacognitive judgments, such as JOLs, have been studied extensively, and empirical data from these experiments will be presented in the next section.

**Judgments of learning.** While EOL judgments occur at the prospective phase of learning, judgments of learning (JOLs) occur during learning when learners attempt to assess their emerging understanding of the topic, and are predictive of subsequent learning performance (Jang & Nelson, 2005). Their role in learning is critical, because the vast majority of empirical research indicates that learners are typically inaccurate at assessing their emerging understanding of a topic (Kelemen, 2000; Nelson & Dunlosky, 1991). How can learners hope to achieve high
learning performance if they are incapable of detecting whether they have sufficiently understood the material? In order to achieve successful learning, learners must be metacognitively aware of the topics they do not understand so that they can alter their metacognitive control behaviors accordingly (such as spending more time studying these topics).

In the current thesis, JOLs were examined primarily because they occur during learning, and therefore can provide insight into the metacognitive processes that actively occur as the learner progresses through a learning episode. Additionally, the collection of both EOL judgments and JOLs can provide insight into how learners’ metacognitive judgments shift from the beginning of the learning episode (before any learning has taken place) to after learning has occurred, and whether EOLs are predictive of subsequent JOLs. Examining metacognitive judgments through the entire course of learning is the best way to gain full access to the complex and constantly shifting metacognitive monitoring and control processes which occur during a learning episode. Most existing research focuses on either EOLs or JOLs independently of each other, which is why the current thesis attempted to examine both. The following section will describe existing empirical research which examines JOLs during learning, and how results from these studies relate to this thesis.

Most existing empirical research examines the effect of monitoring processes on control behaviors. However, some researchers are more interested in the effect of control behaviors on monitoring processes. In an interesting study, Koriat et al. (2006) examined the relationship between JOLs and study-time. The authors theorized that JOLs are sometimes based on feedback from control operations (how much study-time is allocated to a topic), and they set out to determine if JOLs could be directly moderated by study-time. In their self-paced experiment,
participants were given as much time as they needed to learn a set of paired associates and were asked to make JOLs for each pair after the learning session was complete.

Gamma correlations indicated that JOLs decreased with the amount of time spent learning items (i.e., when more time was spent learning an item, participants reported being less confident that they had sufficiently learned the item). The authors attributed these results to the notion that participants were using feedback from control operations to inform their JOLs. Specifically, they used the amount of time they spent learning an item to inform their assessment of how well they understood it. Participants who spent more time learning an item should have made higher JOLs for that item because they devoted more time to learning it and therefore should have a better understanding of it. However, results from this experiment indicated that participants used the amount of time they spent learning an item as an indirect EOL judgment, in that items which required more study-time were inherently more difficult and therefore harder to understand. This would indicate that JOLs are data driven (that is, determined by the ease or difficulty of the item itself).

Koriat and colleagues’ study is important because it offers a new perspective into how metacognitive monitoring and control behaviors interact. Specifically, it demonstrates that learners’ control behaviors can significantly impact their metacognitive monitoring processes. This is important and highlights the need for researchers to closely examine how metacognitive monitoring and control affect one another, and how they interact to impact learning. However, a problem with examining these processes together is that sometimes metacognitive judgments occur quickly and are difficult to capture and assess, and to make meaningful inferences about how they impact metacognitive control. The current thesis attempted to resolve this issue by: (1) prompting for metacognitive judgments throughout a learning session to eliminate the possibility
of missing rapidly occurring processes, and (2) tracking participants’ allocation of study-time throughout the session, to examine how these processes co-occur during learning.

As mentioned in the above section, experiments which utilize paired associates as learning materials are limited by the possibility that findings may not translate to richer learning environments such as classrooms, hypermedia and multimedia learning environments, or intelligent tutoring systems. Taking a more ecologically valid approach to studying metacognition during learning, Azevedo and Cromley (2004) investigated the role of various metacognitive and cognitive processes during hypermedia learning of complex science. Using a mixed methodology pretest-posttest control group design, the authors attempted to discover if training on the deployment of SRL processes can improve learning performance in college undergraduates.

Results from this experiment indicated that extensive SRL training led participants to deploy significantly more SRL processes during learning, and to achieve higher learning performance than participants who received no training. Specifically, judgments of learning showed highly significant differences between groups, indicating that deploying JOLs during learning may lead to increased learning performance. This makes sense, because the relationship between accurate metacognitive monitoring and increased learning performance has been demonstrated in the literature discussed above.

There are several important implications of this experiment. First, these results indicate that the use of JOLs can be beneficial for learners. Being able to accurately assess one’s emerging understanding of the topic is important for making decisions regarding how much time should be spent studying the content. As mentioned above, appropriate allocation of study-time
is crucial for optimal learning. Further, using monitoring processes such as JOLs appears to give learners the potential to optimally increase learning performance.

Another important contribution of this experiment is that it is one of the first of its kind to use an ecologically valid learning environment to examine these processes. Many current empirical studies examine learning of paired associates or short paragraphs which are very dissimilar from the typical learning contexts that learners face (see Dunlosky & Metcalfe, 2009 for a recent review). However, the strength in these kinds of low-level studies is that they allow for some form of experimental control. Using paired associates as learning materials allows researchers to design stringent, trial-by-trial experiments where metacognitive judgments are prompted, learning takes place, and recall is tested. Analyzing the relationship between metacognitive judgments and learning performance is made easier by this simple experimental design. Using an ecologically valid learning environment like the one used in Azevedo and Cromley’s experiment focuses on relevant educational materials, and is beneficial because it presents a learning episode that is familiar to most learners and allows metacognitive monitoring and control processes to occur as they would during typical learning.

In an attempt to blend the attributes of both of these methods, the current thesis combined a trial-by-trial approach, which prompted metacognitive judgments and tracked control behaviors (by recording participants’ allocation of study-time), with a multimedia learning environment in which participants studied complex science. The goal of this method was to use an experimental approach to understand how metacognitive monitoring and control processes occur during naturalistic learning.

**Retrospective confidence judgments.** As discussed in the sections above, learners often use metacognitive judgments such as EOLs and JOLs to determine allocation of study-time.
Many empirical studies, like the ones mentioned above, have examined the predictive accuracy of these judgments on metacognitive control behaviors and learning performance. These judgments, however, do not fully represent the metacognitive operations which occur during learning. Often learners must postdict their learning (retrospectively judge how well they performed on an evaluation after that evaluation has occurred). Theide and Dunlosky (1994) discovered that learners are significantly more accurate at judging their learning after a short delay is imposed between the learning episode and the JOL prompt (delayed JOL) than when the prompt occurs immediately following learning (immediate JOL). Using this knowledge as a foundation, cognitive researchers became interested in the question of whether learners’ judgments could be even more accurate if a metacognitive prompt occurred after learners are tested over the content they just learned. These judgments, called retrospective confidence judgments (RCJs) occur after learning has taken place and solicit learners’ judgments of how likely it is that their responses to evaluative items (e.g., multiple choice, labeling, or free response) were correct.

Metacognitive processes are often difficult to recognize and assess when they occur during learning. However, recent research examining what occurs in the brain when learners use these processes has given great insight into the precise nature of how they occur. An interesting glimpse into the relationship of neurological functioning and RCJs came from Pannu, Kaszniak, and Rapcsak (2005) who examined metamemory in patients with frontal lobe lesions. Studies on individuals with these kinds of lesions indicate that inaccuracies in metacognitive judgments such as RCJs come from poor retrieval from memory resulting from faulty monitoring and control mechanisms, rather than from faulty encoding which occurs with other kinds of neurological dysfunction. In their studies, Pannu and colleagues investigated RCJs in a face-
name retrieval task between brain damaged and healthy participants. For this task, participants viewed pictures of culturally familiar people and were asked to report the name of each person. After each response, participants were asked to make a retrospective confidence judgment by reporting how strongly they believed that they correctly matched the face with the corresponding name.

The authors found that brain damaged participants were significantly less accurate than healthy participants in judging their performance. That is, participants with damage to the frontal lobe were unable to monitor the accuracy of their responses. The authors suggest that the reason why brain damaged individuals and healthy individuals differed in the accuracy of their RCJs is that damage to the frontal lobe causes deficiencies in monitoring mechanisms. The inability to accurately monitor their metacognitive processes significantly impaired brain damaged participants’ ability to judge whether their response was correct or incorrect.

This study is important to the conceptualization of the current thesis. Most importantly, it is one of the first to examine RCJs during learning. Recently a growing interest in RCJs has emerged, but researchers are only beginning to delve into their relationship with metacognitive monitoring, control, and learning performance. The literature reviewed in previous sections demonstrates the high correlation between metacognitive monitoring processes and learning. Therefore, it seems reasonable that researchers should not only examine monitoring processes that occur prospectively (EOLs) and during learning (JOLs), but also after learning has occurred (RCJs), and how these processes relate to study-time allocation and learning performance.

A second implication of this study is that it provides evidence for the notion that metacognitive judgments like RCJs have neurological underpinnings in specific areas of the brain. The goal of this thesis was not to examine the relationship of brain functioning and
metacognitive judgments. However, the findings in the study described above demonstrate that metacognitive judgments like RCJs appear to be bound to specific cortical regions in the brain that are also associated with cognitive processes such as decision making and allocation of resources (Blakemore & Choudhury, 2006; Moore, Schettler, Killiany, Rosene, & Moss, 2009). If these processes occur in the same cortical regions, then it seems that they would both: 1) be similarly affected by other internal processes (for example, an individual’s emotional state), and 2) interact together to influence behavior. For this reason, the current thesis first sought to examine the impact of induced emotional states on learners’ metacognitive judgments, including EOLs, JOLs, and RCJs. Second, it attempted to understand how learners’ metacognitive judgments influenced their metacognitive control behaviors (such as study-time allocation) and learning performance.

**Study-time allocation.** The above review demonstrated the dominant trend in metacognitive research to examine the relationship between metacognitive monitoring and control. Successful learners are those who have high metacognitive awareness and use their awareness to monitor and control their study-time allocation, while unsuccessful learners do not. Vast amounts of empirical research indicate that learners use EOL and JOL judgments to regulate study-time while learning (Dunlosky & Hertzog, 1999; Metcalfe, 2002; Nelson & Narrons, 1990). Appropriate allocation of study-time is a key component of metacognitive control and a vital component of SRL.

Researchers interested in examining study-time allocation often explore how time pressure can affect learners’ decisions about how much time should be spent studying a particular topic. For example, Son and Metcalfe (2000) conducted a series of three experiments to examine the relationship between metacognitive judgments and study-time allocation under
various time constraints. In each of the three experiments, participants were given easy and
difficult texts of varying lengths and were asked to provide EOL judgments for each text. The
authors manipulated the amount of time participants were given to study each text. That is, in
some conditions participants were given ample time to study texts, while in other conditions they
were under high time pressure.

Overall, the results from these experiments demonstrated that when participants were
under high time pressure and insufficient time was given to study each text, they spent
significantly more time studying slides that were judged as easy. In contrast, when participants
were given ample time, they spent significantly more time studying slides that were judged as
difficult.

These results suggested that learners’ metacognitive control behaviors can be directly
mediated by both their own metacognitive judgments and by the time constrains inherent to the
task. Participants in this experiment used their EOL judgments to determine how much time to
allocate toward studying topics under various time constraints. This finding is important because
it suggests that participants recognized which topics would be difficult to learn and altered their
study-time allocation in an attempt to effectively learn the material.

Similar results have been found by Metcalfe (2002) and Metcalfe and Kornell (2003),
who have demonstrated that, when given enough time to study, learners will typically choose to
spend more time studying difficult items than easy items. This is appropriate, as difficult items
should require more attention in order to be understood. With this in mind, what kind of time
constraints should be imposed on learners? In learning environments where some questions are
easy (requiring less study-time) and some questions are difficult (requiring more study-time),
should time constrains be imposed at all? High time pressure can lead learners to feel anxious,
frustrated, and disorganized, and these negative emotions can lead to poor learning performance. However, no time pressure may cause learners to less-actively engage in the task or become bored.

In an attempt to control for these effects, participants in the current experiment used a *self-paced* multimedia learning environment. That is, participants were allowed to decide how much time to allocate toward studying topics associated with text based and inference questions. Existing research demonstrates that in self-paced learning environments, learners are proficient at allocating more study-time to topics that are judged as difficult to learn than topics that are judged as easy to learn (Dunlosky & Theidi, 2004; Theide et al., 2003). Therefore, the current thesis: 1) used log-file data to track participants’ metacognitive judgments and 2) allowed participants to decide how much time to allocate toward studying topics in a multimedia learning environment, to determine if participants allocated more study-time to topics that were judged to be difficult and less understood than topics that were judged to be easy and better understood. The goal was to demonstrate the complex relationship between metacognitive monitoring and metacognitive control during multimedia learning.

The above sections have reviewed empirical literature which examines the relationship between metacognitive monitoring, metacognitive control, and learning performance. These studies are important to the current thesis and to cognitive and educational psychology, because they highlight the complexity of the metacognitive monitoring and control processes that occur during learning. Despite the implications of these studies, they all have one common limitation: they do not consider the impact of learners’ emotional states on each of these processes. The next section provides a theoretical review of the Cognitive-Affective Model of Learning. This model
of multimedia learning is one of the first in its field which attempts to incorporate metacognitive monitoring, metacognitive control, and emotion into a model of SRL.

**Cognitive-Affective Model of Learning**

As the previous review demonstrates, learners who are proficient at regulating metacognitive monitoring and control processes are more likely to achieve deeper, more meaningful learning. However, in order for meaningful learning to occur, students must also feel motivated to complete the task and learn more deeply (Krapp, 1999; Pintrich, 2003). Based on the thesis that exploring, coordinating, and integrating multiple representations of a learning domain can increase interest and motivation, Moreno and Mayer (2007) developed the Cognitive-Affective Model of Learning (CAML) which incorporates motivation and affect.

The CAML (see Appendix A) incorporates sensory, working, and long term memory and the complex interactions which occur between these three memory stores. Like other models of SRL such as the IPT model (Winne & Hadwin, 2008), and the Cognitive Theory of Multimedia Learning (Mayer, 2008), the CAML focuses primarily on the cognitive and metacognitive processes which occur during learning. What sets the CAML apart is its attention to the role of non-cognitive factors in learning with multimedia. The bottom-up arrows indicate the motivational and affective components which are necessary to permit the student to devote attentional resources to the learning task. The top-down arrows indicate the metacognitive self-regulation strategies used to control the cognitive processes needed for understanding (Azevedo, 2008, 2002; Dunlosky & Metcalfe, 2009; Son & Schwartz, 2002). According to the CAML, learners may self-regulate by monitoring their affect and motivation. For example, learners who make a metacognitive judgment that they lack motivation or are experiencing a negative emotion may control these feelings by increasing their engagement with the learning task (Alberto &
Troutman, 1999). Conversely, learners may also use affect to monitor self-regulation. If learners realize they are not being attentive to the learning task, they may use an affective strategy to increase their interest in the task. In this way, learners are constantly using affect and self-regulation to monitor their learning.

While the CAML does acknowledge the role of emotion in learning, it does not offer a clear conceptual explanation for the precise nature of the relationship between emotional states and metacognitive judgments, or how emotions serve to facilitate or constrain. These issues need to be resolved before researchers can hope to have a clear understanding of the complex relationship between emotion, metacognition, and learning. The next section will discuss the implications of the reviewed theoretical assumptions and empirical research on the design of the current thesis.

Implications For The Design of The Current Study

This review provided a theoretical rationale and empirical evidence regarding emotion, metacognitive monitoring, metacognitive control, and the various processes that occur with these complex constructs, along with two models of multimedia learning. The review of empirical literature demonstrated that metacognitive judgments occur prospectively (EOL judgments), during learning (JOLs), and retrospectively (RCJs). Each of these judgments may have different mechanisms underlying their formation. For example, EOL judgments may be influenced by the type of question learners are asked to answer, while JOLs may be influenced by the emotional states learners experience during learning. Conversely, RCJs may be influenced primarily by learners’ motivation to perform well rather than by perceptions of the task itself. Despite these differences, findings from the reviewed studies indicate that each metacognitive judgment plays a role in shaping both learners’ metacognitive control behaviors and overall learning.
performance. What still remains to be understood is how emotional states impact all of these processes during learning. Due to the lack of theoretical or empirical understanding of the effect of emotion on metacognitive monitoring, metacognitive control, and learning performance, the current thesis attempted to induce emotional states and assess the effect of participants’ emotional states on each of these processes.

The above review of the CAML demonstrated that there are still many questions that need to be answered in order to more fully understand the interaction of cognitive, metacognitive, and affective processes that occur during multimedia learning. Including metacognitive monitoring processes (EOL, JOL, and RCJ) and one metacognitive control process (study-time) in the current study of multimedia learning provided a fine-grained look into: 1) the ways in which learners monitor and control their learning of a complex science topic within a multimedia environment, 2) how these four processes influence each other during multimedia learning, 3) how these processes are moderated by learners’ emotional states, and 4) how all of these processes combine to affect learning performance.

Research Questions and Hypotheses

**Research Question 1:** How does induced emotional state and question type affect participants’ metacognitive judgments during multimedia learning?

*Hypothesis 1:*

It was hypothesized that induced emotional state and question type would interact together to affect metacognitive judgments. During trials in which an accelerated heart rate was presented through false biofeedback, it was predicted that participants would perceive that they were in an aroused emotional state. Because arousal during learning is typically perceived as an unpleasant, negative
emotional state, it was predicted that most participants would experience this arousal as anxiety, confusion, or frustration. This perception would cause participants to report significantly lower metacognitive judgments (EOLs, JOLs, and RCJs). During baseline trials (where biofeedback of a resting heart rate was presented) and control trials (where no feedback was presented) it was predicted that participants would make significantly higher judgments because these kinds of feedback are typically perceived as neutral or slightly positive emotional states. It was also hypothesized that question type would affect metacognitive judgments. For trials during which inference questions were presented, participants would report significantly lower metacognitive judgments because these questions are typically more challenging and anxiety-provoking than text-based questions. For trials during which text-based questions were presented, participants would report significantly higher metacognitive judgments. Finally, it was predicted that induced emotional state and question type would interact together to impact metacognitive judgments.

**Research Question 2:** How does induced emotional state and question type affect participants’ study-time allocation during multimedia learning?

**Hypothesis 2:**

Empirical research has concluded that learners use metacognitive judgments to regulate study-time. Therefore, it was predicted that slides which were presented with an accelerated heart rate would elicit low metacognitive judgments, which would result in participants spending significantly more time studying the slide because they would have judged the material as more difficult to learn and harder
to understand. When baseline or no heart rate was presented, participants would be likely to make higher metacognitive judgments, indicating that they perceived the material to be easier to learn and understand. It was predicted that participants would spend significantly less time studying these slides. It was also predicted that participants would spend less time studying slides for which they were be required to answer a text-based question than an inference question, because text-based questions require less effort and are less anxiety-provoking than inference questions. Finally, it was predicted that induced emotional state and question type would interact to affect study-time. Specifically, when participants received an accelerated heart rate, they would perceive both text-based and inference questions to be more difficult than when they received baseline or no heart rate, and they will spend more time studying these slides.

**Research Question 3:** Does induced emotional state and question type affect performance during multimedia learning?

**Hypothesis 3:**

It was predicted that participants would perform better on text-based questions than inference questions because inference questions are typically more challenging and contain emotion-inducing factors which are not contained by text-based questions. It was also predicted that induced emotional state would affect overall learning performance. That is, slides that were accompanied by an accelerated heart rate would induce negative emotional states which would lead participants to perform significantly lower on questions related to the learning material than on slides accompanied by baseline or no heart rate. Also, it was
predicted that there would be a significant interaction between induced emotional state and question type on performance.

**Research Question 4:** How does induced emotional state and question type affect participants’ reported emotional states during learning?

**Hypothesis 4:**

It was predicted that during trials in which an accelerated heart rate was presented participants would report significantly more negative emotions (i.e., anxiety, stress, frustration) and report feeling significantly more aroused than during trials in which a baseline or no heart rate was presented. It was predicted that participants would report significantly more positive emotions (i.e., relaxation, excitement) and report feeling significantly less aroused during trials in which a baseline or no heart rate was presented than trials in which an accelerated heart rate was presented. For question type, it was predicted that participants would report significantly more negative emotions and significantly higher arousal for inference questions than text-based questions.

**Method**

**Participants**

Fifty (N = 50) undergraduate students from the University of Memphis participated in this experiment. The participants’ mean age was 23.3 years (SD = 7.13), and of the entire sample there were 34 females (68%). Their mean GPA was 3.13, with a range of 2.0-4.0. Participants were recruited through classroom solicitation and informational flyers. All participants received $20 for participating in the experiment.
Design

This experiment used a 3 (Induced Emotional State: Accelerated, Baseline, and No Heart Rate) x 2 (Question Difficulty: Text-Based and Inference) within-subjects design. All levels of both factors were counterbalanced across participants.

Stimuli and Software

A researcher-developed linearly-structured self-paced multimedia learning environment comprised of 24 slides about the human circulatory system was presented using Automated Testing System (ATS; Lehman, D’Mello, & Person 2008). ATS is a computer-based testing system which was used for delivering digitally recorded audio and video instructional messages, presenting auditory stimuli, delivering learning content, presenting metacognitive judgments and text-based and inference questions, and recording the following participant interactions: 1) how much time participants allocated to studying each slide, 2) participants’ responses to metacognitive judgments including EOLs, JOLs, and RCJs which were presented on a six-item signal detection scale, and 3) participants’ responses to text-based and inference questions about the content on each slide. The ATS program consisted of a large display window which presented text about the human circulatory system on the left side of the screen and a corresponding static diagram on the right (see Appendix B). The text on each of the 24 slides was congruent in length, with an average of 82.3 words per slide. Adjacent to the text and diagram display window was a narrow window which presented metacognitive judgments and text-based and inference questions. Below this window was an input box which displayed multiple choice radio buttons for responding to metacognitive judgments and answering questions. Participants’ responses were captured when they clicked on one of the multiple choice radio buttons provided in the narrow window. Participants progressed through the program by
using a mouse to click a small navigational arrow displayed in the right hand corner of the screen. A progress bar located above this arrow tracked participants’ progress through the program by shading in green the percentage of slides they had completed, and a timer in the left hand corner of the screen was displayed continuously throughout the session.

The two auditory stimuli used in this experiment were approximately two minutes in duration and were presented binaurally through headphones. These stimuli were initiated when participants opened a content slide and played continuously until they navigated away from the content slide by clicking the navigational arrow at the bottom of the screen. Because the session was self-paced and allowed participants to navigate through the program at their own speed, these digital recordings were programmed to loop continuously for the duration of time participants spent on any particular content slide. This ensured that the presentation of these stimuli was uninterrupted. During baseline trials, participants heard a digital recording of a resting human heart rate (approximately 70 BPM), and during accelerated trials, they heard a digital recording of an accelerated human heart rate (approximately 100 BPM). During control trials, no auditory stimuli were presented. To avoid being abrupt and startling participants, baseline and accelerated recordings began at a low volume and increased in volume over a five-second period before leveling out at a stable volume.

Apparatus

A Reebok Fit Watch 10s strapless heart rate monitor was worn around participants’ non-dominant wrist, and a 4GB USB flash drive was connected to a USB port located on the computer. This heart rate monitor was designed to accurately detect and display the wearer’s current heart rate. However, because previously-recorded baseline and accelerated heart rates were presented to participants (rather than their own heart rate), this function was not used for
The purpose of the watch was simply to cause participants to believe that their heart rate was being collected, recorded, and presented back to them during the session. The auditory stimuli (digitally recorded accelerated and baseline heart rates) were presented binaurally through stereo headphones.

**Materials and Measures**

The paper and pencil materials for this experiment consisted of a consent form (see Appendix C), a demographic questionnaire (see Appendix D), the State-Trait Anxiety Inventory (Spielberger, 1983; See Appendix E), and the Affect Grid (Russell, Weiss, & Mendelsohn, 1989; See Appendix F). The consent form described the experiment, its potential risks, and informed participants that they had the right to terminate the experiment at any time. The demographic questionnaire solicited information concerning age, sex, academic major, GPA, and previous relevant work experience (i.e., nursing, medicine, biology). The State Trait Anxiety Inventory STAI (Cronbach’s alpha = 0.89) is a 40-item self-report instrument used for measuring anxiety in adults. It differentiates between the temporary condition of state anxiety and the long-standing quality of trait anxiety. The Affect Grid (Cronbach’s alpha = .85) is a single item scale which serves as a quick means for measuring affective states along the dimensions of valence and arousal. Instructions for defining valence and arousal on the Affect Grid are intentionally vague so that experimenters can manipulate the grid to serve a wide range of research interests. In this experiment valence was defined as pleasantness versus unpleasantness, and arousal was defined as motivation/interest versus boredom/disinterest.

The computerized materials for this experiment included a six-minute digitally recorded instructional video and a five-minute heart rate recognition task. The instructional video was presented at the beginning of the session and provided a virtual tour of the learning environment,
spoken instructions, and a virtual demonstration of how to use the environment. The heart rate recognition task was presented at the end of the session and was used as a manipulation check to ensure that participants were able to differentiate between digitally recorded baseline and accelerated heart rates. This task presented participants with 10 five-second samples of baseline and accelerated heart rates (five baseline and five accelerated) which were randomly presented. Participants were instructed to listen to each sample and determine which heart rate they just heard by clicking a radio button labeled either baseline or accelerated.

**Experimental Procedure**

Participants in this experiment participated either individually or in a group of two to four. For group sessions, participants were directed to computers which were far enough apart to avoid distraction or conversation during the experiment. The experimental procedure involved the following phases: 1) collection of informed consent and demographic information, 2) completion of the STAI, 3) Affect Grid training and practice, 4) presentation of the instructional video, 5) instructions for using the Reebok wristwatch, 6) the learning session, 7) the heart rate recognition task, and 8) payment and debriefing. Each of these phases will be described in turn.

**Informed consent and demographics.** Each participant, upon entering the lab, was given as much time as necessary to read and complete an informed consent form and demographic questionnaire.

**State-Trait Anxiety Inventory.** After completing the consent form and demographic questionnaire, participants were given as much time as necessary to complete the STAI. The experimenter provided the following instructions:

“The STAI is used to assess both your current and typical feelings. On the first page, a number of statements which people have used to describe themselves are given. Read each
statement and use the 4-item scale to indicate how you feel right now, that is, at this moment. On the second page, you will see another set of statements. Read each of these statements and use the 4-item scale to indicate how you generally feel, that is, how you feel on a typical day. Please remember that there are no right or wrong answers, and you have as much time as you need to complete this assessment.”

After completing this assessment, participants proceeded to the Affect Grid training and practice.

Affect Grid training and practice. All participants spent approximately ten minutes receiving training for using the Affect Grid. To begin their training, participants watched the experimenter use an Affect Grid which was illustrated on a blackboard. The experimenter provided the following instructions:

“Following each trial within this session you will be prompted to complete one Affect Grid. This measure is used as a quick and easy means for you to report your emotional state. The Affect Grid records your emotions on the dimensions of valence and arousal, and you can use a combination of these dimensions to express any emotion you feel. For example, if you place an X in the precise center of the grid, this indicates a completely neutral state. The further to the right you go, the more pleasant, good, or happy the emotion. The further to the left, the more unpleasant, bad, or sad. Starting in the middle and going further to the top, the more activated, engaged, motivated, or interested you feel. The further to the bottom, the more bored, unmotivated, or uninterested you feel. If you were to divide the grid into four equal quadrants, each quadrant would represent a different family of emotions. For example, the top right corner might be excitement, because these emotions are both pleasant and activating. The top left corner might be stress, because these emotions are activating but unpleasant. The bottom left corner
might be sadness, because these emotions are unpleasant and unactivating. Finally, the bottom right corner might be relaxation, because these emotions are unactivating and pleasant. It is important to remember that each box represents a different shade of emotions, with boxes toward the edges of the grid representing extremes and the boxes toward the center of the grid representing milder emotions.”

After these instructions were given, the experimenter allowed participants to ask any questions they had about what they had just learned. Any questions were resolved through discussion with the experimenter. After resolving all questions, participants began the Affect Grid practice procedure and were given the following instructions:

“Now that you have learned how the Affect Grid works, please indicate where you think the emotion frustration would fall by placing an X in one of the boxes on the practice grid in front of you.”

The experimenter assessed participants’ responses (which typically fell in the stress quadrant) to ensure that participants understood how to appropriately use the Affect Grid. Participants who gave unusual responses were prompted to explain their response. If their explanation unveiled a misunderstanding of the use of the Affect Grid, the experimenter provided further instructions and discussion until the misunderstanding was resolved. If their explanation unveiled not a misunderstanding of the Affect Grid, but rather, an unusual emotional response style, this was noted in their file. After completing the Affect Grid training and practice, participants received an instructional video about the learning environment.

**Instructional video for interacting with the learning environment.** The six minute instructional video was comprehensive and detailed. When the video began, participants were
asked to wear headphones so that they could hear the instructional messages being given. The video began with the following instructions:

“The software you will be using in today’s experiment is called Automated Testing System, or ATS. ATS is a computer-based testing system designed to teach you about the human circulatory system and to collect responses from you throughout the session. Before you begin, let’s walk through one trial so that you can become familiar with how to use the software.”

Participants viewed a virtual demonstration of a learner going through one complete trial while using the ATS environment. Verbal instructions were digitally recorded and presented during the demonstration which provided: 1) a detailed explanation of the organization of ATS, 2) declarative and procedural definitions of the three metacognitive judgments participants would be asked to deploy throughout the session, 3) instructions for answering text-based and inference questions, 4) instructions for navigating through the environment (i.e., using the small navigational arrow at the bottom of the screen and only progressing linearly forward), 5) instructions for how and when the Affect Grid should be completed (i.e., on paper and pencil following a prompt from the system), and 6) an explanation of how the progress bar could be used to track their progress within the session. Finally, at the end of the video participants were reminded that the session was self-paced, meaning that they were under no time constraints and could navigate through the system at their own speed.

After participants viewed the instructional video, they were asked to remove their headphones and were allowed to ask questions about using the learning environment. Questions were resolved through discussion with the experimenter, and all participants indicated that they understood the instructions before moving on to the next task.
Instructions for using the Reebok wristwatch. Following the instructional video, the experimenter provided instructions and a demonstration for using the Reebok wristwatch. The following instructions were provided:

“This wristwatch is designed to collect and record your heart rate throughout the learning session. The sensor, which is sensitive to the pulse in your wrist, is located on the back of the watch. Therefore, you must wear the watch with the sensor pressed snuggly against your non-dominant wrist, that is, the wrist of whichever hand you do not write with. Please make sure that the wristwatch is snug enough to be able to detect your pulse without being too tight and cutting off your circulation. Throughout the session, this wristwatch will collect your heart rate and wirelessly transmit this information to a USB drive connected to a port in the computer. This data is then fed into a software package which will simultaneously present your heart rate back through your headphones.

It is important to remember that for some trials you will hear your heart rate, and for other trials you will not. Do not worry if you do not hear your heart rate for some trials, as this is completely normal. Please try to remain as still as possible to avoid disrupting the data. If at any time during the session you feel uncomfortable with this procedure, please alert the experimenter.”

After receiving these instructions, the participants were instructed to strap the wristwatch around their non-dominant wrist, and the experimenter checked to ensure that all participants followed the instructions. Before progressing to the learning session, the experimenter verified that all participants were comfortable and at ease with the procedure.

Multimedia learning session using ATS. After all training, practice, and instructional procedures were complete, participants were asked to put their headphones back on. After
ensuring that participants felt comfortable and ready to begin the session, the experimenter initiated the ATS software and the session began. In this multi-step experiment, ATS prompted participants to complete the following seven steps in order: 1) view a text-based or inference question related to the science content, 2) make an Ease of Learning (EOL) judgment, 3) study the multimedia science content, 4) make a Judgment of Learning (JOL), 5) view the text-based or inference question and provide a response by selecting one of four multiple choice foils, 6) make a Retrospective Confidence Judgment (RCJ), and 7) complete one Affect Grid. Steps one through six were presented and recorded in ATS, while step seven was presented and recorded on paper. Each of these steps will be discussed in turn.

Before beginning the learning session, participants heard the following digitally recorded instructions which were presented in ATS:

“You are now ready to begin the session. The researcher will be here throughout the entire session to answer any questions you may have about the task. If a question about the task or a problem with the system should arise, please address the researcher. However, the researcher cannot answer any questions about the science content itself. You may now click the navigational arrow at the bottom right of the screen to begin. Please try your best, and good luck.”

After hearing these instructions, participants clicked the arrow to begin the first trial. In the first step, participants viewed either a text-based or inference question related to the science content which appeared in a small window on the right hand side of the screen. Text-based questions were conceptually simple and required only a factual re-representation of the information found in the text (i.e., What is the primary function of platelets in the blood?) Inference questions were more conceptually challenging and required participants to bridge two
With age, the aortic valve sometimes accumulates deposits of calcium, the valve becomes stiffened, and the opening narrows. What might be an effect of this situation?) At this time participants were not shown the four multiple choice options for answering the question. In the large display window to the left of the text-based or inference question, participants were given the following instructions for making an EOL judgment:

“Please read the question to your right. After reading this question, please indicate how easily you believe you can learn the content to answer this question by selecting one of the six options.”

Participants used the radio buttons located in the input box below the question to make an EOL judgment on a 6-item signal detection scale ranging from 1 to 6 (1 = I strongly feel this will be difficult to learn, 2 = I somewhat feel this will be difficult to learn, 3 = I slightly feel this will be difficult to learn, 4 = I slightly feel this will be easy to learn, 5 = I somewhat feel this will be easy to learn, 6 = I strongly feel this will be easy to learn). After making their selection, participants clicked the navigational arrow to continue to the content slide.

Participants had as much time as desired to read the content and study the corresponding diagram on each content slide. Additionally, the text-based or inference question which they viewed in step one remained in the top right hand corner of the screen so that they did not have to retain the question in working memory while they studied. Upon opening the content slide, the ATS program presented a recording of either an accelerated, baseline, or no heart rate through participants’ headphones. This recording played continuously until participants navigated away from the content slide by clicking the navigational arrow. Participants heard each of the three heart rates (accelerated, baseline, or no heart rate) for a total of eight trials, yielding a session of 24 trials. The presentation of these stimuli was counterbalanced throughout the session.
When participants navigated to the next slide, the text-based or inferential question and the learning content were removed from the screen. ATS prompted participants to make a JOL by providing the following instructions:

“Please indicate how well you believe you understood the content you just read by selecting one of the six options.”

Participants made a JOL on a 6-item signal detection scale ranging from 1 to 6. (1 = I strongly feel I do not understand, 2 = I somewhat feel I do not understand, 3 = I slightly feel I do not understand, 4 = I slightly feel I understand, 5 = I somewhat feel I understand, 6 = I strongly feel I understand). After making their selection, participants clicked the navigational arrow to continue.

On the next slide, the text-based or inference question was presented again and participants were prompted to select from one of four multiple choice foils presented in the input box. These four foils consisted of the target (the correct response to the question), a near-miss (an option that sounded correct but was not), a thematic miss (an option that followed the theme of the content but was not actually related to the question) and a miss (an option that was not at all related). Participants selected the best option by clicking one of the four radio buttons, and continued to the next slide by clicking the navigational arrow.

Next, ATS prompted participants to make an RCJ by giving the following instructions:

“Please indicate how confident you are that your answer was correct by selecting one of the six options.”

Participants made an RCJ on a 6-item signal detection scale ranging from 1 to 6 (1 = I strongly feel my answer was incorrect, 2 = I somewhat feel my answer was incorrect, 3 = I slightly feel my answer was incorrect, 4 = I slightly feel my answer was correct, 5 = I somewhat
feel my answer was correct, 6 = I strongly feel my answer was correct). After making their selection, participants continued to the last step by clicking the navigational arrow.

For the final step in each trial, ATS prompted participants to fill out one Affect Grid by providing the following instructions:

“Please fill out one Affect Grid on the table beside you. Remember that this grid is used to indicate your current emotional state. When you are finished, flip the grid over and click the navigational arrow to continue to the next trial.”

The completion of the Affect Grid marked the end of one trial. This seven step process occurred for all 24 trials within the self-paced learning session.

**Heart rate recognition task.** After all trials were completed, the heart rate recognition task began. Participants received the following instructions for completing this task:

“During the learning session, the program that recorded your heart rate sampled your heart beating at both baseline and accelerated rates. You will now hear ten samples of baseline or accelerated heart rates collected from your session. Each sample will be presented one at a time. Indicate whether each sample is baseline or accelerated by selecting one of the two options to the right of the screen. After you have made your selection, click the navigational arrow at the bottom of the screen to continue to the next sample. Now please click the arrow to begin.”

Participants spent approximately five minutes discriminating between baseline and accelerated heart rates, and all participants correctly discriminated each sample. After completing the heart rate recognition task, the ATS program was closed and participants were instructed to remove their headphones and wristwatches. Finally, participants filled out a payment form and were compensated and debriefed. All 50 participants successfully completed this task, and therefore each participant’s data was included in this analysis.
Coding and Scoring

ATS was designed to collect and record all participant interactions and upload these interactions to a log file which was created for each participant. Every log file was uploaded to a database for later analysis. The next section describes how this log file data was used to code and score participants’ behavior and performance during the learning session.

Multiple choice questions. For the 24 multiple choice questions, participants were awarded one point for a correct answer and zero points for an incorrect answer. The range of scores per participant was 0-24 since each participant answered 12 text-based and 12 inference questions during the learning session. Six mean scores were collected for each participant: the mean score for overall performance across all 24 slides, one mean score for each level of induced emotional state (accelerated, baseline, and no heart rate), and one mean score for both levels of question type (text-based and inference).

Metacognitive judgments. For each trial within the session, participants provided a response ranging from one to six for each of the three metacognitive judgments (EOL, JOL, RCJ). Using these responses, five mean scores were calculated for each metacognitive judgment. Participants received a mean score for each of the three levels of induced emotional state (accelerated, baseline, and no heart rate) and a mean score for both levels of question type (text-based and inference).

Affect Grid. The Affect Grid was scored using the prescribed scoring method for this measure (Russell et al., 1989). For each of the 24 Affect Grids completed within the session, participants received a valence score and an arousal score. The valence score was taken as the number of the square selected, with squares numbered along the horizontal dimension. These numbers began at the left and counted from 1 to 9. The arousal score was taken as the number of
the square selected, with squares numbered along the vertical dimension. These numbers began at the bottom and counted from 1 to 9 (yielding a 9 x 9 grid). For valence and arousal, participants received a mean score for each of the three levels of induced emotional state (accelerated, baseline, and no heart rate) and a mean score for both levels of question type (text-based and inference).

**Results**

**Research Question 1:** How does induced emotional state and question type affect participants’ metacognitive judgments during multimedia learning?

To answer this question, a separate analysis was conducted for each of the three metacognitive judgments collected during the session. Each of these analyses will be described in turn.

**Ease of learning judgments.** Because EOL judgments occurred early in the session (before ATS presented either an accelerated, baseline, or no heart rate) a one-way repeated measures ANOVA was conducted to compare the effect of question type on participants’ EOL judgments across text-based and inference questions. The results of this analysis indicated that there was a significant main effect for question type, $F(1, 49) = 75.05, p < .001$, partial $\eta^2=.61$. Post-hoc analysis revealed that participants made significantly higher EOL judgments for text-based questions ($M = 4.8$, $SE = .79$) than inference questions ($M = 4.1$, $SE = .94$). That is, participants believed that content associated with text-based questions would be significantly easier to learn than content associated with inference questions.

**Judgments of Learning.** A 3 x 2 repeated measures ANOVA was conducted to compare the effect of induced emotional state (accelerated, baseline, and control) and question type (text-based and inference) on participants’ JOLs. Results indicated that there was a
significant main effect for question type, $F(1, 49) = 145.13, p < .001$, partial $\eta^2 = .75$ (Text based > Inference). There was no significant main effect for induced emotional state. However, there was a significant interaction between induced emotional state and question type, $F(2, 48) = 16.39, p < .001$, partial $\eta^2 = .25$. (see Figure 1).

![Figure 1. Estimated marginal means of participants’ judgments of learning.](image)

**Retrospective Confidence Judgments.** A 3 x 2 repeated measures ANOVA was conducted to compare the effect of induced emotional state and question type on participants’ RCJs. Results indicated that there was a significant main effect for induced emotional state, $F(2, 48) = 11.50, p < .001$, partial $\eta^2 = .19$ (Accelerated > Baseline > Control), and a significant main effect for question type, $F(1, 49) = 217.21, p < .0001$, partial $\eta^2 = .81$ (Text Based > Inference). There was also a significant interaction between induced emotional state and question type, $F(2, 48) = 10.95, p < .001$, partial $\eta^2 = .18$. Post-hoc analyses using a Bonferroni correction indicated that participants made significantly higher RCJs for text-based questions ($M = 5.4, SE = .06$) than inference questions ($M = 4.5, SE = 4.5$) across accelerated, baseline, and no heart rate conditions. For inference questions, participants made significantly higher RCJs when they heard an accelerated heart rate ($M = 4.8, SE = .12$) than a baseline ($M = 4.5, SE = .09$) or control heart
rate ($M = 4.0, SE = .11$), and made significantly higher RCJs for baseline than control heart rates.

For text-based questions, results indicated that there were no significant differences among the three heart rate conditions (see Figure 2)

![Figure 2](image.png)

*Figure 2. Estimated marginal means of participants’ retrospective confidence judgments.*

**Research Question 2:** How does induced emotional state and question type affect participants’ study-time during multimedia learning?

A 3 x 2 repeated measures ANOVA was conducted to compare the effect of induced emotional state and question type on participants’ study-time allocation. The results indicated that there was a significant main effect for induced emotional state, $F (2, 48) = 21.48, p < .001$, partial $\eta^2=.31$ (Baseline > Accelerated > Control) and a significant main effect for question type, $F (1, 49) = 25.17, p < .001$, partial $\eta^2=.34$ (Inference > Text Based). There was also a significant interaction between induced emotional state and question type, $F (2, 48) = 69.62, p < .001$, partial $\eta^2=.59$. Post-hoc analyses using a Bonferroni correction revealed that participants spent significantly more time studying inference questions than text based questions when they heard an accelerated heart rate or no heart rate, but not when they heard a baseline heart rate. Further analysis revealed that participants spent significantly more time studying text-based questions...
when they heard a baseline heart rate than when they heard an accelerated or no heart rate. No other significant differences between conditions were found (see Figure 3).

![Graph showing study-time allocation](image)

*Figure 3. Estimated marginal means of participants’ study-time allocation*

**Research Question 3**: How does perceived emotional state and question type affect learning performance during multimedia learning?

A 3 x 2 repeated measures ANOVA was conducted to compare the effect of induced emotional state (accelerated, baseline, and no heart rate) and question type (text-based and inference) on participants’ learning performance. The results indicated that there was a significant main effect for induced emotional state, $F(2, 48) = 14.24, p < .001, \eta^2=.23$ (Accelerated = Baseline > Control), and a significant main effect for question type, $F(1, 49) = 28.96, p < .001, \text{partial } \eta^2=.37$ (Text Based > Inference). There was also a significant interaction between induced emotional state and question type, $F(2, 48) = 15.73, p < .001, \text{partial } \eta^2=.24$. Post-hoc analyses using a Bonferroni correction revealed that when participants heard no heart rate they scored significantly higher on text-based questions ($M = 85\%, SE = .04$) than inference questions ($M = 55\%, SE = .03$).
Additionally, further analyses revealed that participants scored significantly higher on inference questions when they heard an accelerated \( (M = 83\%, \ SE = .03) \) or a baseline heart rate \( (M = 74\%, \ SE = .03) \) than no heart rate. There were no significant differences in performance on text-based questions across the three levels of induced emotional state (see Figure 4).

![Figure 4. Estimated marginal means of participants’ mean performance.](image)

**Research Question 4:** How does induced emotional state and question type affect participants’ reported emotional states during learning?

Two separate 3 x 2 repeated measures ANOVAs were conducted to compare the effect of induced emotional state and question type on participants’ self-reported valence (pleasantness vs. unpleasantness) and arousal (high motivation vs. low motivation) during the session. Both analyses will be discussed in turn.

**Valence.** The results of this analysis indicated that there was a significant main effect for question type, \( F (1, 49) = 41.49, \ p < .001, \ \text{partial } \eta^2 = .46 \) (Text Based> Inference). However, there was no significant main effect for induced emotional state and no significant interaction (see Figure 5).
Figure 5. Estimated marginal means for participants’ self-reported pleasantness.

Arousal. The results of this analysis indicated that there was a significant main effect for induced emotional state, $F (2, 48) = 7.65, p < .01$, partial $\eta^2 = .14$ (Accelerated =Baseline > Control) and a significant main effect for question type, $F (1, 49) = 6.92, p < .05$, partial $\eta^2 = .12$ (Inference > Text Based). There was no significant interaction between induced emotional state and question type.

Figure 6. Estimated marginal means for participants’ self-reported arousal.
Discussion

Results from this experiment revealed that participants’ metacognitive judgments, study-time allocation, learning performance, and reported emotional states were significantly affected by induced emotional state and question type. The next section will discuss these results, and attempt to provide theoretical rationale for how and why they may have occurred. It will also discuss limitations and potential theoretical and educational implications of the current thesis.

The first point of inquiry for the current thesis was to determine if induced emotional states and question type could significantly impact learners’ ease of learning judgments, judgments of learning, and retrospective confidence judgments. The results suggested that participants’ metacognitive judgments were affected by both their perceived emotional states and by the ease or difficulty of the questions they were expected to answer.

The effect of question type on participants’ metacognitive judgments aligns with current existing research. Results indicated that participants reported significantly lower EOLs, JOLs, and RCJs for trials associated with inference questions than text based questions. This result was expected, as text based questions are conceptually less challenging and can be answered by locating one key sentence within the text. Inference questions are expected to elicit lower metacognitive judgments because they require participants to integrate information from two of more sentences within the text. These results align with findings from various other researchers (Dunlosky & Lipko, 2007; Dunlosky & Metcalfe, 2009; Theide et al., 2003; Leonesio & Nelson, 1990), which posit that learners must be able to accurately discriminate material that will be easy to learn from material that will be more challenging to learn. In the current experiment, participants recognized: 1) that they would experience more difficulty learning content associated with inference questions than text based questions (EOL), 2) that they achieved lower
understanding of material associated with inference questions (JOL), and 3) that their responses to inference questions were more likely to be inaccurate (RCJ).

The finding that participants reported consistently lower EOLs, JOLs, and RCJs for inference questions than text based questions suggests that they may have used feedback from initial metacognitive judgments to inform subsequent metacognitive judgments. For example, items that are judged to be difficult to learn are typically associated with lower understanding of the material (Koriat, 2008), which may impair learning performance. In this experiment, when participants were prompted to make an EOL and reported that a topic would be difficult to learn, they also perceived that they did not understand the material well, and were less confident that their responses to questions about the material were correct. This result is promising, because it offers evidence that prompting participants to engage in metacognitive processes before, during, and after learning has occurred can help them become more metacognitively aware of their progress. In order to achieve successful learning, learners need to be aware of both the difficulty of the topic and their emerging understanding of the topic so that they can engage in effective metacognitive control, such as allocating the appropriate amount of time toward studying the topic.

Understanding the effect of question type on participants’ metacognitive judgments is important. However, examining the effect of emotional states on these processes can be even more revealing about the complex interaction of phenomena that occur during learning. Overall, participants’ emotional states had very complex effects on their reported JOLs and RCJs, which require further discussion.¹

¹ Ease of learning judgments occurred before emotions were induced through false biofeedback. Therefore, the effect of induced emotional state is only discussed for JOLs and RCJs.
Results indicated that induced emotional states had no significant effect on learners’ JOLs. This finding did not support the hypothesis that participants’ JOLs would shift depending on their emotional state (i.e., participants would make less confident JOLs when they heard an accelerated heart rate than when they heard a baseline or no heart rate). There is no existing literature which provides empirical evidence or a theoretical explanation for how emotion might impact JOLs during multimedia learning, which makes interpreting these results somewhat challenging. Perhaps induced emotional states did not have a significant effect because participants were asked to make an immediate rather than a delayed JOL. In self-regulated learning literature, the delayed JOL effect (Theide & Dunlosky, 1994) claims that learners’ JOLs are more accurate when an approximately 30 second delay is imposed between studying the content and receiving the JOL prompt. In this experiment, it is possible that prompting participants to make a JOL immediately after studying the content did not provide them with enough time to accurately assess their emotional state and their current understanding of the material, and how their emotions might have impacted their understanding. In that case, participants may have made an unrefined evaluation regarding how well they understood the content. Perhaps if a delay has been imposed between studying the content and prompting for a JOL, participants may have been better equipped to make a thorough metacognitive evaluation of how well they understood the content.

Results from participants’ RCJs indicated that participants made significantly higher RCJs when they heard an accelerated heart rate rather than a baseline or no heart rate. This finding is interesting and, at first glance, contradicts existing theories (Schutz & Davis, 2000; Zeidner, 2007) which claim that high physiological arousal can lead to negative emotions and cause learners to feel less confident in their ability to accurately respond to questions about the
material. However, results from the Affect Grid indicate that when participants heard an accelerated heart rate they were likely to report feeling highly motivated. This outcome is consistent with existing theories which claim that high motivation is associated with high confidence and self-efficacy (Pekrun, 2006; Zeidner, 2007). It seems that participants in this experiment perceived that an accelerated heart rate indicated that they were motivated to perform well on the task. Their perception of high motivation may have caused them to feel more confident, which may have translated to higher RCJs. However, this finding raises one important question: If participants perceived to be highly motivated when they heard an accelerated heart rate and, therefore, made higher RCJs for these trials, then why did they not also make higher JOLs for these trials? One potential explanation for this result relates to the delayed JOL effect. For example, participants were prompted to make a JOL immediately after studying the content, which may not have allowed them enough time to accurately assess their understanding of the material. Conversely, RCJs were prompted after participants made a JOL and read and selected from four multiple choice foils in order to answer the text based or inference question. Because a moderate delay was imposed between studying the content and being prompted to make an RCJ, participants may have had more time to evaluate their understanding of the material and the effect of their emotions on their performance, and were therefore more confident in their ability to accurately answer the question. Examining participants’ monitoring accuracy is beyond the breadth of this thesis. However, these results suggest that further analyses should be conducted to determine if participants’ RCJs were more accurate (i.e., more closely correlated with actual learning performance) than their JOLs. Were participants’ RCJs more accurate predictors of learning performance? Further, were participants more accurate when they heard an accelerated heart rate than a baseline or no heart rate? Answers to these questions would be interesting and
might help explicate the precise impact of learners’ emotional states on metacognitive judgments.

Now that the effect of question type and induced emotional state on participants’ metacognitive judgments has been discussed, this section will now turn to the effect of these processes on participants’ study-time allocation. The findings were complex, and there is little existing empirical work which could offer a precedence for explaining how they may have occurred, so some speculation was required to attempt to explain these interesting results.

As expected, participants spent significantly more time studying slides associated with inference questions that text based questions. This is appropriate, as current research indicates that successful learners should spend more time studying items that are judged as difficult to learn than items that are judged as easy to learn (Dunlosky & Hertzog, 1999; Metcalfe, 2002, 2009; Nelson & Narrons, 1990). Recall that in this experiment, participants reported significantly lower EOL judgments for inference questions than text based questions. The discovery that participants spent more time studying slides that were judged as difficult to learn is important and very exciting, because it suggests that they used feedback from metacognitive judgments to govern their metacognitive control processes. As stated in the review of the literature, the ability to integrate metacognitive monitoring and control processes is a fundamental component of successful self-regulated learning.

The analysis of the effect of induced emotional state on study-time allocation yielded an unexpected finding. It was predicted that participants would spend significantly more time studying slides when they heard an accelerated heart rate than when they heard a baseline or no heart rate. Presumably, participants would perceive to be in a state of high stress when they heard an accelerated heart rate and would attempt to compensate for this stress by allocating more time
to studying the slide. However, results indicated that, overall, participants spent significantly more time studying slides when they heard a baseline heart rate than when they heard an accelerated or no heart rate.

What were the affective processes that contributed to this interesting finding? Were there different affective processes that were associated with hearing a baseline heart rate that may have affected participants’ study-time allocation? Perhaps the best way to answer these questions is to examine the interaction of induced emotional state and question type, as well as data from participants’ self-reported emotional states on the Affect Grid.

Results from the induced emotional state/question type interaction indicated that when participants heard either an accelerated or no heart rate, they spent significantly more time studying inference questions than text based questions. As stated above, this was an appropriate strategy because participants had already reported that slides associated with inference questions would be more difficult to learn and, therefore, should be given more attention. However, when participants heard a baseline heart rate, they spent significantly more time studying text based questions than inference questions. This is a confusing result with very little existing empirical or theoretical guidance for explaining why it occurred. Perhaps an explanation can be found by examining the mood-as-information theory (see Schwarz & Clore 2003), which states that individuals use feedback from their emotional states to determine their behavior. Positive affect is a signal that all is going well, while negative affect is a signal that something has gone wrong. In learning contexts, the feeling that “all is well” can lead learners to focus attention on their emotional state rather than on the task (Pekrun, 2006). Participants’ self-reported valence, overall, did not differ significantly across the three levels of induced emotional state. However,
participants did report significantly higher valence when they were asked to answer a text based question rather than an inference question.

It is possible that when a baseline heart rate was paired with a text based question, participants perceived that learning the material would be easy and that all was well (i.e., “My heart rate indicates that I am calm, the question is easy. I am competent to answer this question”). In this situation, participants may have become less focused or driven to learn the material. Rather than engaging in meaningful processing of the multimedia content, they may have focused their attention on their emotional state, which may have led participants to linger on these slides. Therefore, the finding that participants spent more time on these slides may not be indicative of actual study-time allocation. Rather, it may simply indicate participants’ reluctance to navigate to a new slide and possibly transition out of a state of positive valence.

In support of this hypothesis, results indicated that participants’ study-time allocation decreased significantly when a baseline heart rate was paired with an inference question (rather than a text based question). This finding, compared with results from the Affect Grid which indicate that participants reported significantly lower valence when they were asked to answer an inference question, may suggest that when participants were no longer in a state of pleasant affect, they resumed focusing on the task rather than on their emotional state, resulting in decreased study-time.

These findings are complex and clearly require further investigation in order to more fully understand the interaction of metacognitive and affective processes which may have produced these interesting results. The above discussion has highlighted the fact that there are still many questions that need to be answered about the relationship between emotion and study-
time allocation. Keeping these questions in mind, the following section will discuss the role of induced emotional state and question type on participants’ learning performance.

Overall, results indicated that participants’ performance on text based questions did not differ significantly across all three levels of induced emotional state. That is, participants achieved high performance on text-based questions regardless of which heart rate they heard. This was expected because, as stated above, text based questions are less conceptually challenging and should be associated with high learning performance. In this experiment, the correct answer could be easily found by locating one key sentence within the text. Therefore, induced emotional state should not have had a significant impact on participants’ performance on these questions.

Inference questions were more conceptually challenging, and therefore, it was predicted that participants’ performance on these questions would be significantly affected by induced emotional state. Specifically, it was predicted that participants would perceive to be in a state of anxiety when they heard an accelerated heart rate and that, subsequently, their learning performance would suffer. This prediction was not supported; in fact, results indicated that participants’ performance suffered the greatest when they heard no heart rate. That is, when participants were presented with either an accelerated or baseline heart rate (paired with an inference question) they achieved significantly higher learning performance than then they were presented with no heart rate. At first glance these results are confusing and seem to lack any kind of theoretically driven means for explaining them. However, results from the Affect Grid may provide answers regarding the impact of participants’ emotional state on learning performance.

Recall that instructions for the Affect Grid prompted participants to report high arousal when they felt interested or motivated in the task, and to report low arousal when they felt bored,
disinterested, or unmotivated. Results from the Affect Grid indicated that participants reported significantly higher arousal when they heard accelerated and baseline heart rates than when they heard no heart rate. In addition to this finding, participants also reported significantly higher arousal for inference questions than text based questions. These results, in combination, indicate that participants may have experienced higher motivation or interest when an accelerated or baseline heart rate was paired with an inference question. A vast amount of empirical literature indicates that motivation is a vital contributor to learning performance, and learners who are motivated typically achieve higher learning performance than those who are unmotivated (Boekearts, 2001; Boekaert et al., 2000; Hulleman, Durik, Schweigert, & Harackiewicz, 2008; Moos & Azevedo, 2008; Pekrun, 2006). It seems that participants’ high motivation during trials in which an inference question was paired with an accelerated or baseline heart rate may have translated to increased learning performance. In sum, this finding supports many existing theories which claim that motivation is a key component to achieving successful learning (Boekearts, 2001; Pekrun, 2006; Pekrun et al., 2009; Tooby & Cosmides, 2009).

The goal of this discussion was to attempt to explain the complex findings from the current thesis. First, it examined the role of induced emotional state and question type on participants’ metacognitive judgments, and suggested that the difficulty of the question participants were required to answer may have had a greater impact on their metacognitive judgments than induced emotional state. Next, it examined the role of these two processes on participants’ study-time allocation, and suggested that the effect of induced emotional state on participants’ study-time seemed to be mediated by the kind of question they were required to answer. Finally, this discussion examined the effect of induced emotional state and question type on learning performance, and suggested that high motivation experienced by participants when
an accelerated or baseline hear rate was paired with an inference question may have improved participants’ performance on these trials.

These findings are complex but very interesting. The lack of existing theory or empirical research to help explain these findings demonstrates the need for future exploration to be conducted to answer the questions which arise from this thesis. However, researchers interested in examining these questions need to be aware of the limitations which accompanied this experiment, and which pervade most emotion-based research in learning contexts.

**Limitations**

There are several limitations related to this experiment. First, the use of a single data collection method rather than using and converging multiple methods was a significant limitation. This experiment relied entirely on the accuracy of log file data which was generated by the ATS system for each participant. While these log files provided a great deal of information about participants’ metacognitive judgments, study-time, and learning performance during the learning session, they did not provide additional information which could have helped untangle some of the unexpected results. For example, video and audio data could have supplemented this experiment by recording participants’ behaviors such as body posture, facial expressions, and hand gestures. These behavioral manifestations have been found to be important indicators of on-going cognitive and affective processes which occur during learning (Azevedo, Johnson, Chauncey, & Graesser, in press; D’Mello, Graesser, & Picard, 2007).

Second, this experiment was limited by the typical challenges of studying emotions during learning. The biggest of these challenges is the fact that emotions are complex and transient ways of being. Because emotions occur quickly and can change rapidly, it is possible for the kind of emotion, or the intensity or expression of the emotion, to change at any given
moment (Schutz et al., 2004). These emotional shifts can occur too fast for both the researcher and the participant to recognize. In this experiment, abrupt changes in participants’ emotional state may have drastically altered their metacognitive judgments and study-time, which could have had a significant impact on their performance. Being unable to detect these emotional shifts may have limited the researcher’s ability to make accurate inferences regarding the effect of induced emotional state on metacognition, study-time allocation, performance, and reported emotional state.

Lastly, the method of inducing emotions also comes with a host of its own challenges. Most importantly, emotional states which are experimentally induced and occur in a laboratory setting may be qualitatively different than those that occur naturally during studying or test-taking. It is possible that the results from this laboratory experiment may not be replicable in a similar classroom experiment where metacognitive judgments, study-time and performance are examined as students’ emotions occur and shift naturally rather than being induced. Finding ways to induce emotional states which are similar to those that occur naturally, or finding ways to examine naturally occurring emotional states without interfering or altering the emotions themselves would dramatically improve the interpretability of the results from this experiment.

Although there were several limitations to this experiment, the results have implications for improving existing theories of emotions and learning, and for improving the way learning occurs in students of all ages. The next section will discuss each of these in turn.

**Theoretical Implications**

The results from this experiment highlight the need for existing theories to be expanded upon to include the role of emotion and motivation during self-regulated learning.
Most existing theories (Boekaerts, 2001; Beokaerts et al., 2000; Moreno & Mayer, 2007; Pekrun, 2006; Pekrun et al., 2009) recognize that emotion and motivation play an important role in learners’ deep understanding of complex material. However, many of these theories do not offer an explanation for how emotion and motivation combine to affect self-regulation, behavior, and learning performance. For example, Moreno and Mayer’s Cognitive Affective Model of Learning (Appendix A) indicates that motivation and affect (as well as self-regulation) are processes that are inextricably bound to learning. This model lacks, however, an explanation of how motivation and affect relate to other key processes that occur during learning, including their effect on: (1) integration of new information with prior knowledge, (2) allocation of attentional resources to the learning task, (3) metacognitive judgements regarding the perceived difficulty of the task, learners’ emerging understanding, and their confidence in their responses, (4) the appropriate (or inappropriated) allocation of study-time, and (5) overall learning performance. While the findings from this experiment do not address all of these issues, its use of experimental manipulation to induce emotional states during learning helps unveil answers to some. This experiment provides evidence that positive emotions and high motivation can lead learners to make more confident metacognitive judgments, to persist longer when the material is challenging, and to achieve higher performance. Future research directed toward improving existing theories of multimedia learning should focus on determining if these results are replicable in multimedia learning environments designed to teach about other complex topics (i.e., ecology, computer literacy), if they exist in other developmental levels (such as middle- and high-school students or adult learners), and which cognitive processes co-occur with affective and motivational processes during learning. Finding answers to these questions will lead to a more comprehensive, accurate, and predictive model of multimedia learning.
Educational Implications

This experiment suggests that learners’ emotions can significantly constrain or facilitate learning performance. As such, it is important that results from this experiment serve to improve the conceptualization and design of multimedia and hypermedia learning environments and intelligent tutoring systems. Results from this thesis supplant the need for computerized learning environments to be sensitive to these dynamic and complex processes in order to help learners achieve deep learning (Azevedo, 2008; D’Mello et al., 2007). For example, intelligent tutoring systems which use pedagogical agents to scaffold learners’ understanding of complex science topics might benefit from the use of physiological measures which can detect shifts in learners’ emotional and motivational states on-line. If a learner shifts to a negative emotional state (i.e., stress, boredom), a system which is sensitive to these shifts could help learners transition out of these emotional states by modeling, prompting, and scaffolding appropriate self-regulatory processes.

How can computerized learning environments accurately record and assess learners’ emotional states? Current research is being conducted to determine if affect sensors embedded in intelligent tutoring systems can detect the emotional states that occur during learning (D’Mello, et al., 2007). If learners’ emotions can be automatically detected and assessed in situ during learning, can intelligent tutoring systems help learners become metacognitively aware of the emotions they experience while they learn? If learners are aware of their emotions, can they regulate those emotions? More importantly, can recognizing and regulating their emotions help learners become more metacognitively aware of their emerging understanding of the topic, which may lead to more meaningful learning? If so, it seems that future research must
necessarily be directed toward developing computerized testing systems which can be sensitive and responsive to learners’ emotions.

**Conclusion**

In sum, this experiment demonstrates the need for more empirically-driven research directed toward understanding of the role of metacognition, emotion and motivation during multimedia learning. As theoretical, conceptual, and educational implications and methodological techniques are improved, the elusive role of emotion may be disambiguated, leading researchers to more fully understand the consequences of emotion on learning. When a clear conceptualization of the way emotion impacts cognition, metacognition, self-regulation, and learning performance is formed, the way that the complex relationship between emotion and learning is examined will be significantly improved.
References


Appendix A

The Cognitive-Affective Model of Learning
Appendix B
Automated Testing System

Display window which depicted text and static diagrams about the circulatory system.

Text based or inference question which was displayed continuously.

Participant input box where metacognitive judgments and answers to questions were collected.

Progress bar which displayed participants’ current progress within the environment.
Appendix C
Informed Consent

Participant ID: ______________

EXAMINING THE COMPLEX NATURE OF EMOTION, METACOGNITION, AND STUDY-TIME IN MULTIMEDIA LEARNING

Identification of Project
The role of emotion on self-regulated learning, metacognition, and study-time allocation while learning about complex science topics.

Statement of Age of Participant
I state that I am over 18 years of age, am in good physical health, and wish to participate in a program of research being conducted by Amber Chauncey (advisor: Dr. Roger Azevedo) at the University of Memphis, Department of Psychology.

Purpose
The purpose of this research is to examine the role of emotion in the deployment of self-regulated learning processes during learning about complex science during multimedia learning.

Procedures
The procedures will involve 1 session, during which I will be asked to learn about the human circulatory system with multimedia. During the session, I will be asked to (1) complete a participant questionnaire and (2) learn to distinguish between various levels of arousal through biofeedback, (3) provide metacognitive judgments at various time intervals, (4) answer questions pertaining to the material I am learning, (5) report my emotional state at various time intervals. I will be asked to verbalize my thinking during the entire process. The session will last approximately 90 minutes. I understand that the session will be audio- and video recorded.

I am providing my initials (_______) to indicate that I am interested in being contacted in the future to participate in other studies related to this project on learning about the human circulatory system with multimedia.

Confidentiality
All information collected in the study is confidential, within the limits allowed by law, and my name will not be identified at any time. I understand that my face will never be recorded on the videotape. I give the Cognition and Technology Lab (CTL) permission to show segments of the videotapes at conferences and presentations. A numeric code will be used as identification on data collection materials. Once data are collected, this code will be used for maintenance and analysis of data. Pseudonyms will be used in publications and conference papers. According to APA guidelines, after 5 years, all data will be destroyed.

Risks
I understand that there are no known risks from this experiment.

Benefits: Freedom to Withdraw and Ask Questions
I understand that the experiment is not designed to help me personally, but that the investigator hopes to learn more about the how emotion affects self-regulation during multimedia learning about a complex science topic. I understand that I will receive 90 minutes credit toward the two-hour requirement for my General Psychology (Psyc 1200) course. I understand that The University of Memphis does not have any funds budgeted for injury, damages, or other expenses. I understand that I am free to ask questions and/or to withdraw from participation at any time without penalty. If you have any questions regarding your rights, you may contact the Chair of the Institutional Review Board for the Protection of Human Subjects at 901-678-2533.
Amber Chauncey  
Dr. Roger Azevedo  
University of Memphis  
Department of Psychology  
Psychology Building, room 403/409  
Memphis, TN 38152  
Tel: 901-678-3036  
dchuncey@memphis.edu

___________________________________________

Printed Name of Participant

___________________________________________

Signature of Participant

___________________________________________

Date

Informed Content (Continued)
Appendix D

Demographic Questionnaire

Name

___________________________________________________________

Gender

______________________________

Age

______________________________

College

___________________________________________________________

Academic Major

___________________________________________________________

Class (check one)  Freshman (    )  Sophomore (    )  Junior (    )  Senior (    )

Biology Courses previously taken (if any)

<table>
<thead>
<tr>
<th>Course Title</th>
<th>Course Number</th>
<th>Was the human circulatory system covered? (yes or no). If yes, what aspects were taught?</th>
</tr>
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<tbody>
<tr>
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</tbody>
</table>

Relevant work experience (related to health or medicine):

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________
Appendix E

State-Trait Anxiety Inventory

Subject ID:____________

A number of statements which people have used to describe themselves are given below. Read each statement and use the following scale to indicate how you feel right now, that is, at this moment. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Not at all</td>
<td>Somewhat</td>
<td>Moderately so</td>
<td>Very much so</td>
</tr>
</tbody>
</table>

1. I feel calm.
2. I feel secure.
3. I feel tense.
4. I feel strained.
5. I feel at ease.
6. I feel upset.
7. I am presently worrying over possible misfortunes.
8. I feel satisfied.
9. I feel frightened.
10. I feel comfortable.
11. I feel self-confident.
12. I feel nervous.
13. I am jittery.
15. I am relaxed.
16. I feel content.
17. I am worried.
18. I feel confused.
19. I feel steady.
20. I feel pleasant.
State-Trait Anxiety Inventory (Continued)

Subject ID:____________

Read each statement and use the following scale to indicate how you generally feel. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe how you generally feel.

1 2 3 4
Almost never Sometimes Often Almost Always

_____21. I feel pleasant.
_____22. I feel nervous and restless.
_____23. I feel satisfied with myself.
_____24. I wish I could be as happy as others seem to be
_____25. I feel like a failure.
_____26. I feel rested.
_____27. I am “calm, cool, and collected.”
_____28. I feel that difficulties are piling up so that I cannot overcome them.
_____29. I worry too much over something that really doesn’t matter.
_____30. I am happy.
_____31. I have disturbing thoughts.
_____32. I lack self-confidence.
_____33. I feel secure.
_____34. I make decisions easily.
_____35. I feel inadequate.
_____36. I am content.
_____37. Some unimportant thought runs through my head and it bothers me.
_____38. I take disappointments so keenly that I can’t put them out of my mind.
_____39. I am a steady person.
_____40. I get in a state of tension or turmoil as I think over my recent concerns and interests.
Appendix F

The Affect Grid

The Affect Grid

You use the "affect grid" to describe feelings. It is in the form of a square—a kind of map for feelings. The center of the square (marked by X in the grid below) represents a neutral, average, everyday feeling. It is neither positive nor negative.

The vertical dimension of the map represents degree of arousal. Arousal has to do with how wide awake, alert, or activated a person feels—indeed, independent of whether the feeling is positive or negative. The top half is for feelings that are above average in arousal. The lower half for feelings below average. The bottom represents sleep, and the higher you go, the more awake a person feels. So, the next step up from the bottom would be half awake/half asleep. At the top of the square is maximum arousal. If you imagine a state we might call frantic excitement (remembering that it could be either positive or negative), then this feeling would define the top of the grid.

The right half of the grid represents pleasant feelings. The farther to the right the more pleasant. The left half represents unpleasant feelings. The farther to the left, the more unpleasant.

If the "frantic excitement" was positive it would, of course, fall on the right half of the grid. The more positive, the farther to the right. If the "frantic excitement" was negative, it would fall on the left half of the grid. The more negative, the farther to the left. If the "frantic excitement" was neither positive nor negative, then it would fall in the middle square of the top row, as shown below.
Other areas of the grid can be labeled as well. Up and to the right are feelings of ecstasy, excitement, joy. Opposite these, down and to the left, are feelings of depression, melancholy, sadness, and gloom. Up and to the left are feelings of stress and tension. Opposite these, down and to the right, are feelings of calm, relaxation, serenity.

EXAMPLE: Suppose, instead, that you were only mildly surprised but that the surprise was a mildly pleasant one. You might put your mark as shown below.

Feelings are complex. They come in all shades and degrees. The labels we have given are merely landmarks to help you understand the affect grid. When actually using the grid, put an X anywhere in the grid to indicate the exact shade and intensity of feeling. Please look over the entire grid to get a feel for the meaning of the various areas.

EXAMPLE: Suppose that you were just surprised. Suppose further that the surprise was neither pleasant nor unpleasant. Probably you would feel more aroused than average. You might put your mark as shown.

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