

**COMPLEX RELATIONS BETWEEN
METACOGNITIVE JUDGMENT AND
METACOGNITIVE CONTROL IN SELF-
REGULATED LEARNING**

by

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Abstract

This study explores whether and how the relationship between metacognitive monitoring and metacognitive control in self-regulated learning (SRL) is associated with personal factors such as motivation, personal epistemology, metacognitive awareness, and other individual difference variables. An eye tracking system was used to accurately capture data pertaining to metacognitive monitoring and control in SRL processes while participants studied then restudied some basic concepts of Number Theory using gStudy, a multi-featured software learning tool. This study yielded three significant findings. First, 37 of the 75 participants allocated more restudy time to information they judged not well learned, and 38 people allocated more restudy time to information they judged well learned. This result is not aligned with the dominant model of metacognitively guided restudying proposed by Dunlosky and Herzog (1998) which claims that learners allocate more study time to information they judge difficult. Second, three personal factors were statistically detectably associated with the relation between people's judgments of learning and their allocations of restudy time: monitoring, achievement, and calibration. These represent two categories of learner characteristics: metacognitive awareness and achievement-related factors. Third, individual differences underlying self-reports about metacognitive control operations are fundamentally different from those underlying on-the-fly metacognitive control. This study reveals the dual-process character of online metacognition, different mechanisms in online metacognition versus self-reported metacognition. It also illuminates some limitations of self-report methodologies in measuring SRL in real time and the importance using state-of-the-art technologies in research on real-time SRL processes.

Dedication

I dedicate this dissertation to my parents, Li Zhizhen and Sha Shengzhi.

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Chapter 1

Introduction

The first chapter has two goals. First, I will present the general research question that this dissertation research is intended to address, briefly delineate the origin of the central issue by concisely presenting the key challenges in contemporary research in self-regulated learning and metacognition, as well as the main theoretical constructs involved. Second, an overview of the subsequent chapters will be presented in which the key theoretical and methodological aspects of this study will be outlined.

Self-regulated learning – Core Feature of Lifelong Learning

Lifelong learning seems to be a standard phrase used to characterize what people need in today's information era. A consensus among educators appears to be that, to be lifelong learners, people are supposed to be educated to have a great variety of learning skills ranging from being able to access the internet to gather necessary information to strategies of problem solving. In this sense, equipping students with skills for lifelong learning is a major goal of contemporary education. Among factors important for lifelong learning in the eyes of educational psychology researchers, motivation and self-regulation are two central determinants (Boekaerts, 1997; Schober, Finsterwald, Wagner, Lüftenegger, Aysner, & Spiel, 2007). These skills are viewed as not only crucial for managing one's own learning during formal school education but also for updating one's knowledge after leaving school (Boekaerts), the essential demand of life-long learning. However, having effective skills for learning is one matter; productively regulating the appropriate use of those skills is another. Thus, lifelong learners are supposed to be able

to regulate their learning processes productively and effectively, namely, to self-regulate learning (SRL). What are core skills for productive SRL? What factors might affect use of those skills? These fundamental issues need investigation so that teachers can effectively foster students' metacognitive skills, and so that educational researchers can better model internal and external factors underlying metacognition and SRL.

In order to answer these important questions, it is first necessary to figure out what SRL is, what the key elements in SRL processes are, how students self regulate their learning, and so on. SRL has been an active research area in the field of educational psychology since the mid-1980s (Zimmerman, 2001). The emergence of self-regulated learning research can be attributed to the original attempt to address a fundamental issue for fostering students' lifelong learning capabilities, that is, how students become masters of their learning processes. Although it can be understood that self-regulating capabilities are vital to become lifelong learners, SRL cannot be simply referred to as either a mental ability or an academic performance skill; instead, it should be understood as a self-directive process through which learners' mental abilities are transformed into specific task-related academic skills. SRL has been studied under various theoretical umbrellas. Accomplishments from a variety of theoretical stances are encapsulated in the book edited by Zimmerman and Schunk (2001). The commonalities of those SRL theories converge on theorizing about two fundamental issues in relation to SRL: What is self-regulated learning or how can self-regulated learners be identified? And, how is SRL measured?

Currently, Zimmerman (2001) offers the most widely accepted definition of SRL which is that SRL is a process whereby learners are metacognitively, motivationally, and

behaviorally active participants in their learning processes. This statement embraces three key features of SRL processes: metacognition, motivation, and behavior. A basic consensus is that productive SRL will be proportional to the accuracy and lack of bias in metacognitive monitoring (Winne, 2004). Thus, metacognition alongside other two factors formulates the core of the SRL construct. To my knowledge, however, comprehensive studies that systematically integrate these three essential elements of SRL – metacognition, motivation and behavior – are still lacking.

Complex Relationship between Metacognitive Monitoring and Control – The Focus of the Study

Metacognition refers to people's knowledge about their cognitive and memory processes, and how they put that metacognitive knowledge to use in regulating their information processing and behavior (Koriat, 2007). According to Winne (1996), metacognition has two basic components – *metacognitive monitoring* and *metacognitive control*. These are the pivots on which SRL turns. Metacognitive monitoring relies on learners' subjective judgments of their degree of learning before, during, and after study. Metacognitive control is deciding how to act based on the products of metacognitive monitoring, which accordingly determines the progress of learning (Winne, 2001).

Dunlosky and Hertzog's discrepancy-reduction model (1998) is a widely published attempt to address the association between metacognitive monitoring and control in learning processes, that is, the control function of metacognition (Koriat, 2007). Specifically, that model tries to explain how people's metacognitive judgments of learning (JOLs, an output of monitoring) guide their strategic allocation of study time and items selected for study (i.e., metacognitive control). According to this model, first,

learners tend to spend more study time on items they judged to be difficult to learn. Second, in the case of self-paced study in particular, study continues until the perceived degree of learning meets or exceeds a desired level of strength, referred to as “the norm of study.” In this sense, the discrepancy-reduction model essentially concerns the relationship between monitoring and control in terms of learners’ study time allocation strategies (Son & Schwartz, 2002).

However, several subsequent studies revealed that the relationship between metacognitive judgment and control is not always as simple and linear as the discrepancy-reduction model predicts. For example, Thiede and Dunlosky’s studies (1999, 2004) enriched the discrepancy-reduction model by introducing various conditions under which learners were found to display study strategies different from what the discrepancy-reduction model predicts. For example, they found that when learners were presented with an easy performance goal (e.g., learn a list of 30 items but be tested on 10 of the 30 items), they tended to select easier rather than difficult items for restudy.

Other studies revealed that learners’ study time allocation is affected by factors other than metacognitive judgments. In the discrepancy-reduction model, the effects of those contextual factors on control of study strategies are guided by the “norm of study” since, according to Koriat (2007), this threshold is set on the basis of various motivational factors such as the stress on accurate learning versus fast learning.

The discrepancy-reduction model has been modified by taking into consideration various characteristics of learning environments such as the extent of time pressure and learning goals set by the instructor. Therefore, a logical deduction is that, besides these contextual factors, learners’ internal personal factors could be assumed to affect the

control function of metacognition, namely, the relations between metacognitive monitoring and metacognitive control. Personal factors can include people's motivational beliefs, personal epistemology, and other individual difference variables. To my knowledge, however, current research on metacognition has not yet investigated issues with respect to the role of learner's motivational beliefs (e.g., goal orientations, self-efficacy beliefs), epistemological beliefs (e.g., attitudes toward simple knowledge, quick learning), metacognitive awareness (e.g., of strategies for monitoring study), and others. This dissertation research is intended mostly to expand the horizon of metacognition research by exploring the role of such personal factors in the association between metacognitive monitoring and control in SRL processes. A theoretical model that conceptually links metacognition to these personal factors will be built through reviewing relevant literature in Chapter 2.

As noted previously, productive SRL is theorized to be proportional to the absence of bias and errors in metacognitive monitoring (Winne, 2004). This statement essentially suggests that as long as self-regulating learners are able to make accurate subjective judgments of their cognitive processes against imposed or self-set standards, they will choose appropriate learning strategies or study tactics to metacognitively control current learning toward a goal. This assumes learners have sufficient regulation strategies/tactics in long-term memory and the learning environment provides the option for them to exercise control. However, modifications to the discrepancy-reduction model have partially adjusted this simple, linear way of thinking regarding the regulative function of metacognitive judgments in selecting cognitive strategies.

Thus, the central hypothesis of the present study is that self-regulated learners' accurate metacognitive judgments may not necessarily lead to appropriate metacognitive control over their cognitive operations, specifically time allocation or items selected for restudy, because the control function of metacognitive monitoring is affected by learners' motivational and epistemological beliefs, metacognitive awareness, and other context- and subject-specific individual difference variables. In theory, testing this hypothesis will lead not only to advances in current models of metacognition but also provide an opportunity to integrate the basic components of a SRL process: metacognition, motivation, and behavior, as well as other personal factors such as epistemological beliefs.

Testing this hypothesis required me to make use of the advanced technologies to inspect learners' online, real-time cognitive and metacognitive processes such as making judgments of learning and exercising metacognitive control over learning processes (e.g., selecting and allocating study time to individual information objects in the learning material). Those state-of-the-art technologies will be introduced in subsequent chapters.

Overview of the Chapters

The literature review in Chapter 2 will present my model of the role of motivation and personal epistemology in moderating the effects of metacognitive monitoring on metacognitive control in SRL processes. The model will be based on the conceptual framework of self-regulated learning plus contemporary models of metacognition and motivation. The fundamental assumption of self-regulated learning is that self-regulated learners are agents (Martin, 2004; Winne, 2004). The role of metacognition, motivation, and other personal psychological factors in shaping learners' self-regulated learning behavior will be explored from the perspective of Bandura's view of human agency

(Bandura, 2001, 2006). In other words, the concept of agency will provide a theoretical window for viewing the association between learners' personal beliefs (i.e., motivational and epistemological beliefs), their cognitive attentional processes and use of cognitive strategies. For example, measuring metacognitive control in this study will involve computing learner's restudy time allocation. Study time allocation essentially represents allocation of attention – cognitive resources. In this sense, effects of learners' motivational and epistemological beliefs on the relations between metacognitive judgment and control of learning strategies (e.g., study time allocation) can be accounted for in terms of existing studies on the influence of motivation on attentional processes and use of cognitive strategies (Dweck, Mangels, & Good, 2004).

As stated previously, the research questions in this study are concerned with the interplay among three key constituents of SRL– metacognition, motivation, and behavior. This elicits the necessity of measuring learning behavior – patterns of how learners engage with information that operationalize learners' cognitive and metacognitive processes. Thus, in chapter 2 current methodologies for measuring SRL will be critically reviewed to rationalize the use of innovative approaches to obtaining unobtrusive data on learners' actual learning behaviors. The advanced technologies used in this study include a newly developed software system called gStudy, and eye tracking technology. These technologies make it possible to obtain accurate, real-time observations of cognitive operations learners apply to learning materials as they study.

The methodology used in this research is presented in chapter 3. In addition to descriptions of the sample and the questionnaires used to measure several sets of individual difference variables, emphasis will be placed on how dependent variables are

measured and computed by means of eye tracking technology. Since this is an exploratory study, the dependent variable will be defined in different ways and various samples to enhance the reliability and validity of the research. Specifically, the pattern of restudy time allocation can be defined as both a continuous and a categorical variable. This affords using various statistical analysis techniques with the same data to investigate the multi-faceted complex relations between metacognitive judgment and metacognitive control in SRL processes. Chapter 4 presents the results in two sections. The first section will be about how the regulatory function of metacognitive monitoring over study time allocation was influenced by learners' individual difference variables. The second section will be concerned with the comparison and contrast between learners' self-reports of learning strategy use and their actual use of the strategy. In Chapter 5 the results will be discussed to interpret the key findings of the present research. The empirical findings will be discussed in light of contemporary self-regulated learning theories, theories of metacognition, and the fundamental theories under which they are subsumed. For example, the view of dual-character of SRL – aptitude and event – will be examined in terms of the difference between learners' self-perception of learning and their actual learning behaviors.

Chapter 2

Theoretical Model and Literature Review

The purpose of this research is to empirically examine the relation between metacognitive monitoring and metacognitive control, and assess the extent to which it may be affected by learners' motivation, personal epistemology, general metacognitive knowledge and skills, as well as other personal psychological processes emerging in self-regulated learning (SRL). Chapter 2 reviews relevant literature to forge a theoretical account of these relationships in eight sub-sections. Section 1 is about the general definition and several main models of SRL, and the theoretical base underlying SRL research – the notion of *human agency*. The importance of researching metacognition as an essential element of SRL processes will be deduced from the concept of agency. The focus in Section 2 is on metacognition: its definition, components, and the main models. The main issues in metacognition research are briefly reviewed in Section 3. Key research questions emerging in this area are presented in Section 4 rather than being put forth in the end of the chapter. Both Section 5 and 6 deal with the relations between SRL and (a) motivation, as well as (b) epistemological beliefs. Since this dissertation attempts to innovatively employ a computer-assisted SRL system and eye tracking technology alongside traditional self-report measures of SRL as a process, Section 7 will be devoted to theoretical rationales and existing studies regarding how to empirically assess SRL as a process (or event). A brief summary of the chapter will be given on Section 8.

Simply, the literature review will involve two basic aspects along which SRL research has unfolded since it emerged three decades ago: conceptualization and operationalization (Boekaerts & Corno, 2005). It is widely acknowledged among SRL

researchers that existing research has made great progress in conceptualizing SRL. However, the area is struggling to advance methods for operationalizing (measuring) SRL (Perry & Winne, 2006).

Self-Regulated Learning and Its Theoretical Foundation

Multi-faceted Definition of Self-Regulated Learning

Carver and Scheier (1990) claim that “human behavior is a continual process of moving toward various kinds of mental goal representations, and that this movement occurs by a process of feedback control” (p. 3). According to this view, human behavior is conceived of as the product of an internal guidance system that is inherently organized; thus, the mechanism underlying human behavior is a system of self-regulation (Carver & Scheier, 1990, 1998). According to Boekaerts (2005), self-regulation refers to a complex, superordinate set of functions located at the junction of several psychological areas including research on cognition, problem solving, decision making, metacognition, conceptual change, motivation, and volition. Self-regulation also can be defined as “self-generated thoughts, feeling, and actions for attaining academic goals” (Zimmerman & Schunk, 2004, p. 323). Although multiple conceptualizations of the construct of self-regulation can be found in the literature, most researchers agree that self-regulation refers to multi-component, iterative, self-steering processes that target one’s cognitions, feelings, and actions, as well as features of the environment to adjust in the service of one’s goals (Boekaerts & Cascallar, 2006).

The construct of self-regulated learning is subsumed under a general concept of self-regulation (SR) (Boekaerts, 2005). Models of SRL are the direct outcome of deliberate restriction of the scope of SR to learning processes. Defining the concept of

SRL has not been a simple and straightforward task (Boekaerts, 2005). Scholars with different theoretical origins emphasize slightly different aspects of SRL from different perspectives such as operant theory, phenomenological views, social cognitive theory, information processing theory, Vygotsian views, and so forth (Zimmerman & Schunk, 2001).

These are not the only categorizations of SRL models. Puustinen & Pulkkinen (2001) grouped Pintrich and Zimmerman's SRL theories and research together under the same umbrella of social cognitive theory. There are three other influential SRL models: Boekaerts' model of adaptable learning, Borkowski's process-oriented model of metacognition, and Winne's four-stage model of SRL.

According to Puustinen and Pulkkinen, these models represent two kinds of definitions of SRL: a goal-oriented definition and a metacognitively weighted definition. The definitions of the models of Boekaerts, Pintrich and Zimmerman characterize SRL as a goal-oriented process. These models stress the self-generated nature of SRL and propose that cognitive alongside motivational, emotional and social factors underlie the self-regulatory processes. Borkowski's and Winne's models view SRL as a metacognitively governed process emphasizing the adaptive use of cognitive tactics and strategies to learning tasks.

Next, the focus of the literature review will be placed on the social cognitive model of SRL and Winne's model of SRL. It will be seen that definitions of SRL that systematically integrate metacognition, motivation and behavior have become dominant.

Social Cognitive View of SRL

Schunk and Zimmerman's views of SRL are rooted in the tenets of social cognitive theory (Schunk, 2001; Zimmerman, 1998, 2000; Zimmerman & Schunk, 2004). The view holds that SRL has two defining features: (a) SRL essentially results from learners' self-generated thoughts and behaviors that are directed toward attaining learning goals they set forth for themselves, thus it is goal-directed; (b) self-regulation is not a general disposition but situationally specific and highly context dependent. These two features are rooted in the core idea of social cognitive theory that personal cognition is reciprocally determined by behavioral and environmental factors (Bandura, 1986; Zimmerman & Schunk).

Due to reciprocal interactions between personal cognition and the environment, self-regulation is not viewed as a general trait or a particular level of cognitive development but rather as highly context specific. Thus, in educational practices teachers should not expect students to engage effectively in self-regulation equally under all circumstances. Why? The key to the contextual specificity of SRL is the central construction in Bandura's theory: perceived *self-efficacy beliefs* – beliefs about one's capability to accomplish a specific task (Bandura, 1986). Unlike self-concept reflecting a general belief about one's competence in a general area rather than regarding a specific learning task (e.g., "I am good at math."), self-efficacy refers to specific and situational judgments of capabilities for doing a specific thing (e.g., "I believe I can learn the Division Theorem well."). The situational specificity of self-efficacy suggests that self-regulation is inherently highly context dependent. It also can be inferred under the social cognitive model that SRL is partially characterized by students' motivational beliefs

(such as goal orientations, task value, beliefs of control learning, etc) where particularly self-efficacy beliefs play a crucial part in understanding the nature and process of SRL.

Due to the situational view of self-efficacy beliefs and its importance for self-regulation, SRL cannot simply be interpreted theoretically and operationally as a disposition or general ability. What are the implications for theorizing and measuring SRL from the perspective of social cognitive theory? This dissertation research considers this question.

In the social cognitive model of SRL, self-regulation usually involves three key sub-processes: *self-observation*, *self-judgment*, and *self-reaction* (Schunk, 2001). These sub-processes are not mutually exclusive but interact and collectively underlie a unified self-regulation process. Self-regulated learners are theorized to observe the online or dynamically changing state of their learning and motivate themselves accordingly by self-observation – deliberate attention to one’s behaviors. However, self-observation alone usually is not sufficient to sustain motivation because it depends on outcome and efficacy expectations. This demonstrates the importance of self-efficacy and outcome expectations to activating and maintaining learners’ self-regulation of cognitive engagement in learning.

In my opinion, the notion of self-observation conceptually corresponds to the essential concept shared in various SRL theories – monitoring that underlies in the second subprocess, self-judgment. Based on self-observation of their behaviors, learners compare their present learning with their learning goals. Thus, self-judgment refers to comparing one’s current state of progress with the learning goal. The third subprocess or determinant of SRL, self-reaction, involves several cognitive operations such as goal

setting, self-efficacy perceptions and metacognitive planning (Zimmerman, 1989). Self-reactions to goal progress yield evaluations and the effects of evaluations on motivation are mediated through learners' self-efficacy belief (Schunk, 2001). For example, Schunk claims that negative evaluation will not necessarily decrease motivation if learners believe they are capable of improving learning. That clearly suggests, according to the social cognitive model of SRL an important role for learners' self efficacy beliefs. A detailed review will be presented in the later sections of the effect of each of the key components of motivational beliefs on SRL in general and information processing in reading in particular.

Winne's Model of SRL – Information Processing View

Compared to the social cognitive theoretical model of SRL, Winne's model of SRL places more weight on cognitive aspects (Boekaerts, 2005). He conceptualizes SRL in terms of three main features (Winne, Jamieson, & Muis, 2002). First, SRL is a form of cognition. Since cognition is impossible for researchers to inspect directly, assessing it in SRL must rely on inferences grounded in researchers' operational definitions of SRL and its features. Like other forms of cognitions, SRL fundamentally depends on the contents of long-term memory and on cognitive operations while SRL proceeds. Second, SRL is a manifestation of agency even when SRL processes unfold automatically, below consciousness. Two assumptions underlying this claim are (a) automatic regulatory actions (other than physiological reflexes) were deliberately designed in the learner's history, and (b) automated regulatory actions can be inspected and modified under some appropriate conditions. The view of characterizing SRL as agentic entails that self-regulating learners are supposed to have motivation to self generate a goal and actively

approach that goal in the learning process. The conception of human agency will be discussed in-depth in a subsequent section. Third, two principally different activities comprise SRL, metacognitive monitoring and metacognitive control. In Winne's words, these are the pivots on which SRL turns. In my view, that recognition of the central role of metacognition in fueling SRL processes is one of the two striking features of Winne's model.

The second striking feature of Winne's SRL model is its recognition of a dual character of SRL. In Winne's model, SRL can be measured as an aptitude and/or an event (process). SRL as aptitude suggests there is a relatively enduring personal trait that can be used to predict one's future performance. Aptitude measures of self-regulation are designed to aggregate self-regulatory responses over time and circumstances (Perry & Winne, 2006; Zimmerman, 2008). In contrast, an event is considered like a snapshot that essentially represents a sampling point in a larger time-domain process of development (Winne & Perry, 2000). Winne's four-phase model offers an event approach to measuring SRL by examining students' efforts to self-regulate before, during, and after a focal event. Zimmerman (2008) claimed that measuring SRL as a process/event can assess sequential dependency of responses and thereby enable making causal inferences about online changes in self-regulation in real time. SRL as event is the focus in this dissertation research in which real time, online aspects of SRL such as motivation and metacognition were measured while they occurred.

The idea of SRL's dual character, in my view, is not only concerned operationally with how to measure SRL, but theoretically with how to conceptualize the nature of SRL. Researchers who more or less agree on operationism (Feest, 2005) would argue that the

essence of the concept of SRL, to a degree, depends on the way(s) we measure it. As a result, the dual character of SRL essentially converges on a single construct according to operationism. Although elaborative inquiry into this debate is beyond the scope of my research, it actually is related to the main challenges SRL researchers have faced since the outset of SRL research: the imbalance between the proliferation of SRL “theories” and little methodological innovation in SRL research. This point is aligned with the claim that “Modeling SR has so far been more an analytic activity than an empirical one, in part, because we have lacked tools for gathering data that are critical to mapping events that constitute SR.” (Winne, 2005, p. 236)

In Winne’s model, SRL as an event spans three necessary phases and an optional phase (Winne, 2001). Self-regulated learning begins with phase 1, defining the task. This yields two inputs for subsequent processing: *task conditions* and *cognitive conditions*. The former is situational information about the task, say, the teacher’s requirements or the layout of a text. The latter includes at least three aspects (a) domain knowledge of the task stored in the long-term memory; (b) self-recognition of previous performances in relation to this kind task; and, (c) memory of strategies used with similar tasks in the past. A key cognitive feature related to three elements of cognitive conditions is memory. On the basis of self-generated perceptions of the task in Phase 1, self-regulating learners set learning goals in Phase 2. Once goals are framed, tactics or strategies stored in learners’ long-term memory may be activated to meet those goals in Phase 3. A crucial cognitive operation in Phase 3 is monitoring the process of engagement by comparing the current state of learning with the goals set in the previous phase. This phase parallels self-judgment in Zimmerman and Schunk’s social cognitive model of SRL. A product of a

learner's judgment about an ongoing performance is internal feedback about the amount and rate of progress towards goals (Butler & Winne, 1995). This internal feedback plays a vital role in guiding learners in completing a task. Therefore, it appears to be logical to say that the appropriateness of internal feedback, to a large degree, determines how productive a self-regulated learner would be, and, thus, the learner's achievement (Butler & Winne, 1995). In Winne's model, Phase 4 is optional; in my view, however, it is actually quite significant for productive SRL. In Phase 4 learners have opportunity to adapt schemas that configure how SRL will proceed in similar future tasks (e.g., adjusting conditions that determine when a tactic is appropriate).

According to Winne's model, each phase involves five types of information summarized by an acronym COPES – Conditions, Products, Operations, Standards, and Evaluations. For example, cognitive conditions are the products (or outputs) generated from defining a task in Phase 1. These products function as conditions for setting goals in Phase 2. In Phase 3, goals are used as standards by which learners' current state of learning is monitored giving rise to evaluations.

Common Features of Various Models of SRL

Various models of SRL share three principles (Boekaerts, 2005): (a) Self-regulated learners are actively and constructively engaged in a process of meaning making; and their thoughts, feelings, and actions are adaptive to their learning and motivation as needed. (b) Biological, developmental, contextual, and individual difference factors may interfere with or support efforts at regulation. (c) Self-regulated learners are capable generating and using standards as goals and subgoals that direct their learning. According to Zimmerman (2001), various SRL theories also converge on the

assumptions that self-regulated learners are able to: (a) personally improve their ability to learn through selective use of metacognitive and motivational strategies; (b) proactively select, organize, and even create advantageous learning environments; and (c) play a significant role in choosing the form and amount of instruction they need.

Both sets of assumptions about the nature of SRL, in my opinion, concern a fundamental meta-theoretical element intrinsic in all SRL models – the construct of agency. In other words, self-regulating learners are agents who are self-proactive and self-organizing (Bandura, 2001; Martin, 2004). In the literature in SRL, the widely acknowledged definition of SRL given by Zimmerman is that self-regulating learners actively participate in their learning processes metacognitively as well as motivationally and behaviorally. This definition embraces the defining elements of the notion of agency. Boekaerts (1997) pointed out that SRL is not only a complex, demanding, and deliberate, but simple, habitual, and automatic. The idea of agency as self-regulation sheds more light on the role of consciousness in SRL.

Human Agency – Theoretical Base of SRL

Zimmerman's definition of SRL highlights the central role of metacognition in the conceptual framework of SRL. According to Koriat (2007), the basic epistemological assumption of the role of metacognition in cognitive operations is the view of human being as an active organism with agency in a prominent position: "self-controlled processes have measurable effects on behavior" (Koriat, p. 292). Furthermore, Martin (2004) claims that "the self as agent is pervasively implicit in most writings on the topic of self-regulated learning, as it is in the larger psychological literature on self-regulation"

(p. 135). Thus, this section will examine the concept of human agency because it plays a pivotal role in understanding the nature of SRL and the relevant features of it.

Bandura's emphasis on human agency in his social cognitive theory (1986) suggests that individuals are proactively engaged in their development. According to Bandura, key to the notion of agency is that individuals are assumed to possess self-beliefs that enable them to control their thoughts, feelings, and action. Furthermore, human agency refers to an emergent capability of individual human beings to make choices (i.e. setting forth ideas and goals) and to act on these choices constituted primarily through interaction between brain activities and sociocultural contexts (Bandura, 2001; Martin, 2004).

The essence of Bandura's theory of agency has four core features (Bandura, 2001, 2006): *intentionality*, *forethought*, *self-reactiveness*, and *self-reflectiveness*. Intentionality represents a power to originate actions for given purposes which is the key feature of personal agency. "To be an agent is to intentionally make things happen by one's actions" (Bandura, 2001, p. 2). An intention refers to not only an expectation or prediction of future actions but also a proactive commitment to bring them out.

Forethought suggests that human behavior is motivated and directed by anticipated goals and outcomes, as well as planning. An agent is supposed to be able to take appropriate actions and to self-regulate motivation, affect, and action through goal setting. Bandura (2001) argues that future events cannot directly lead to current motivation and action because they actually do not exist. However, foreseeable future events can be converted into current motivators and regulators of behavior through cognitive representations of those events in the present. In other words, projected goals

and anticipated outcomes motivate and direct human behavior through the ability to bring anticipated outcomes to bear on current activities.

Self-reactiveness suggests that “An agent has to be not only a planner and forethinker, but a motivator and self-regulator as well” (Bandura, 2001, p. 8). In other words, agents are assumed to have not only the deliberative ability to make choices and action plans, but also the ability to act on appropriate courses of action and to motivate and regulate their execution. Self-directedness links thought to action through self-regulatory processes in which self-monitoring one’s pattern of behavior and the cognitive and environmental conditions under which action occurs is the first step (Bandura). People’s motivation, affect, and action are self-regulated by a set of self-referent subfunctions which include self-monitoring, performance self-guidance through personal standards, and corrective self-reaction (Bandura).

Finally, self-reflectiveness entails that agents possess the metacognitive capability to reflect upon oneself, thereby generating self-efficacy that is the foundation of human agency. “People are not only agents of action but self-examiners of their functioning.” (Bandura, 2001, p. 10) Self-reflectiveness represents agents’ metacognitive capability to subjectively judge their online state of learning against the goals as standards they intentionally set with shaping from external feedback from peers or teachers. Detailed discussion on the essence and the foundational philosophy of human agency in Bandura’s social cognitive theory is beyond the scope of this dissertation. However, it should be noted that agency is both determined and determining, and has philosophical connections with Piagetian constructivism and Vygotskian socioculturalism as well as determinism (Martin, 2004).

In sum, these four core features of agency enable people to take responsibility for their self-development, adaptation, and self-renewal (Bandura, 2001). In my opinion, the first two core features are essentially associated with the role of motivation in human behavior; the last two features essentially imply the importance of people's metacognitive knowledge about and capability to self-monitor and control cognition, motivation and behavior.

The idea of agency is inherently associated to another foundational concept in psychological sciences – consciousness. Consciousness is the very substance of mental life because “A functional consciousness involves purposive accessing and deliberative processing of information for selecting, constructing, regulating, and evaluating courses of action” (Bandura, 2001, p. 3). According to Metcalf and Greene (2007), the implication of agency is that people are able to monitor their agency, that is, to metacognitively monitor when and whether they are in control to make things happen intentionally (motivationally). It can be inferred from these ideas that agents' metacognitive capabilities and motivation are inherently intertwined in SRL. Self-regulating learners are assumed to exercise agency by consciously setting their learning goals, metacognitively monitoring properties of their engagement in goal-directed tasks, and choosing optimal strategies they think enable them to achieve their goals in the given conditions (Winne & Hadwin, 2007).

Thus, the four core features of agency converge on two essential components of SRL: metacognition and motivation (Zimmerman, 2001). Therefore, to theoretically and empirically look into the nature and process of SRL in a comprehensive way it is vital to understand these key components of SR, as well as the association between them. SRL

research has revealed a great amount about relations between SRL and motivation (Schunk & Zimmerman, 2007), and between SRL and metacognition (Zimmerman, 1995; Winne, 1996). However, comprehensive studies on relations between metacognition and motivation in SRL processes are still rare in the literatures on SRL and metacognition.

Therefore, investigating the role of motivation and other personal factors in metacognition in SRL processes is the general purpose of this dissertation research. To address this issue, logically, it is necessary first to review what is known about how metacognition functions in SRL processes. In the next section, I will primarily focus on metacognition – the essential component of SRL according to Winne (1997). Based on the review the literature on metacognition, particularly the relationship between metacognitive monitoring and metacognitive control, it is expected that the research questions addressed in this dissertation research will have a firm foundation.

Metacognition – An Essential Component of SRL

Starting with the definition of metacognition, this section will discuss several key issues in relation to the nature of the multi-faceted concept of metacognition and its vital role in understanding SRL. Then, I will examine main issues in current research on metacognition. The emphasis will be placed on the intricate relationship between metacognitive monitoring and metacognitive control – two definitional cognitive operations of metacognition (Winne, 1997) so as to rationalize the general research question that this dissertation research addresses.

Models of Metacognition

Metacognition research covers many and various areas across education and cognitive psychology. As a result, we can find many slightly differing definitions of

metacognition in the literature. John Flavell, the pioneer who introduced Piaget's child development theory to North America (Siegler & Crowley, 1991), coined the term metacognition and offered the first definition: "One's knowledge concerning one's own cognitive processes and products or anything related to them..." (Flavell, 1976, p. 232). Koriat (2007), in his recent comprehensive work on the relation between metacognition and human consciousness, also offered a definition of metacognition which reflects today's mainstream in the line of cognitive psychology research. Metacognition refers to the study of what people know about their cognitive and memory processes, and how they put the metacognitive knowledge to use in regulating their information processing and behavior. What can be inferred from Koriat's definition about the nature and components of this construct? The next section reveals metacognition is a multi-faceted concept consequently needing to be conceptualized in various dimensions and at different levels to delineate a relatively complete profile of its features. Current research on the constituents of metacognition can be summarized in three models: a two-level model, a two-operation model, and a two-facet model.

Two-Level Model of Metacognition

Flavell's theory of metacognition (1971) is rooted in his seminal work on metamemory, particularly the monitoring and control of one's learning and remembering (as cited in Koriat, 2007). Building on Flavell's work, Nelson and Narens (1990) further established a conceptual framework for metacognition that has been adopted across various research areas. In their framework, cognitive processes can occur at two levels: the object-level and the meta-level.

The basic cognitive operations relative to learning and knowledge acquisition such as encoding, rehearsing, and retrieving occur at the object level. Object-level operations that are thoughts about an external world then become the objects of higher order operations (Hacker, 1998). In other words, the cognitive operations at the object-level are monitored and controlled by cognitive processes at the meta-level. The latter generates the information used to control the object level of cognition in a top-down fashion. Information about the state of the object-level is developed at the meta-level through conscious or unconscious monitoring operations. Meanwhile, instructions generated at the meta-level are transmitted to the object-level so as to realize the control function of metacognition as Figure 1 shows.

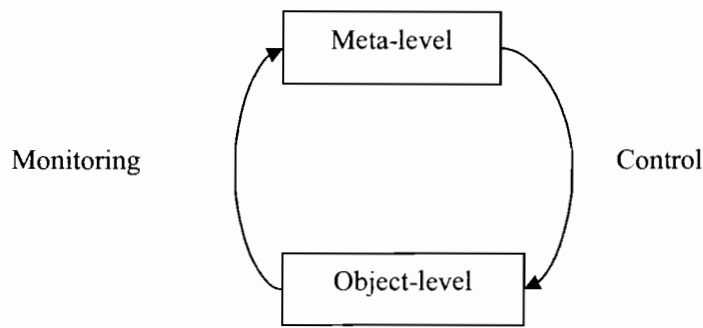


Figure 1. Information Flow Between the Two Levels of Metacognition

This view of the relationship between the object level and the meta-level embraces two intertwined facets of metacognition – *knowledge objects* and *cognitive operations* (Winne, 1996). It should be noted that the distinction between object-level processing and meta-level processing is relational, not absolute, because the same type of processing can occur either as object-level or as meta-level (Nelson, 1997). For example, Dunlosky, Serra, Matvey, and Rawson (2005) conducted a study in which participants

were first asked to make subjective judgments about the likelihood of recalling studied items in a future test (called judgments of learning, JOLs), then to rate their confidence in the accuracy of each judgment (called secondary-order judgment, SOJ). In this case, participants' subjective judgment of their current state of learning is a cognitive operation at the meta-level, since the object of that operation is a studied item which is at the object-level. However, JOLs as the object level for SOJs where SOJs represent meta-level processing. Therefore, the level – object or meta – is relational. The concept of judgments of learning will be elaborated in a later section as one of the key variables in this study.

Two Basic Cognitive Operations of Metacognition: Monitoring and Control

One may ask how these two levels are linked, or how information flows between the object-level and the meta-level. According to Winne (1996), the flow of information between the two levels is realized through two operations – metacognitive monitoring and metacognitive control. Metacognitive monitoring about learning refers to learners' subjective judgments of the degree or features of learning before, during, and after study. Metacognitive control is deciding how to act based on the products of metacognitive monitoring, and this control determines the progress of learning (Winne, 2001).

Metacognitive monitoring inherently entails criteria against which object level information can be examined; metacognitive control, as the second cognitive operation in metacognition, is how the meta-level information arising from monitoring the object level regulates behavior (Winne, 1996). One may further ask how these two operations are linked in a SRL process and what the relation is between them. The second part of this matter will be reviewed in detail in a separate section focusing on that issue.

In Winne's model of SRL, monitoring and control form a condition-action rule, that is, IF-THEN-ELSE representation. For example, IF a learner perceives by monitoring that the current state of learning met a condition or a set of conditions, THEN tactic A (a particular action) would be enacted; or, ELSE tactic B would be carried out to adapt the current state to the goals. To be able to complete the above sequence of cognitive operations, it appears that the learner should possess necessary conditional knowledge that can inform when to enact actions that appear as THENs and ELSEs. This suggests that exercising metacognition involves applying knowledge about the self and cognitive processes.

Two Facets of Metacognition – Knowledge about Cognition and Regulation of Cognition

The above analyses indicate that metacognition refers to knowledge and beliefs about one's cognition, as well as ability to regulate one's cognition. So, metacognition is composed of two facets: *knowledge about cognition* and *regulation of cognition* (Schraw, & Dennison, 1994). The former refers to the knowledge about one's cognitive processes; the latter refers to the capabilities of planning, monitoring, and controlling our cognitive processes (Veenman, Van Hout-Wolters & Afflerbach, 2006).

Under the term metacognitive awareness, Schraw and Dennison detailed the two components of metacognition in their influential work on empirically measuring metacognition as knowledge and a trait-like ability. In their analyses, knowledge about cognition is composed of three sub-processes: *declarative knowledge* (knowledge about self and study strategies), *procedural knowledge* (knowledge about how to use strategies in a given situation), and *conditional knowledge* (knowledge about when and why to use strategies). Regulation of cognition concerns five component skills for regulating

individual learning: *planning, information management strategies, monitoring, debugging strategies, and evaluation*. Schraw and Dennison's work not only conceptualizes metacognition by categorizing the constituents of it, but is instrumental in measuring knowledge and capability as an aptitude that endures and is quite resistant to change (Veenman et al., 2006).

Relation between Metacognition and Cognition

Beyond structural features of metacognition according to these various perspectives, it is still necessary to further examine relations between metacognition and cognition. Metacognition has been referred to as cognition of cognition, knowledge about one's cognitive process, as well as skills of regulation of cognition (Nelson, 1999). Nelson further claims that "Metacognition is defined as the scientific study of an individual's cognitions about his or her cognition. As such, metacognition is more of a subset of cognition than something other than cognition." (p. 625). Veenman, et al. (2006) also pointed out that metacognition draws on domain knowledge, since it is very hard to have adequate metacognitive knowledge of one's competencies in a domain without substantial domain-specific knowledge. Such knowledge allows a learner to conceptualize relevant concepts and theories in a domain, intrinsic difficulties of a domain, and what is irrelevant. In other words, learners need subject matter knowledge to effectively apply metacognitive knowledge (i.e., declarative, procedural and conditional knowledge) and to know when they need to do so.

Winne (1996) pointed out that individual differences in domain knowledge influence the degree to which students deliberately self regulate their learning. His point of view was that students' degree of expertise in a domain can affect metacognitive

elements of SRL in two ways. First, the more extensive one's domain knowledge is, the less is the need to exercise one's self-regulation of study strategies and tactics while engaging in complex learning tasks. Experts' control of their cognitive activities in learning is inherently embedded within domain knowledge. Since knowledge at the object level is sufficient, experts do not need to entirely rely on metacognitive knowledge and skills to overcome obstacles as composed to novices who lack sufficient domain knowledge.

Taken together, this leads to two points. First, if one can automatically and effectively apply domain knowledge to accomplish cognitive tasks, there is little need for self-regulation. Second, when experts' domain knowledge is not sufficient for automatically completing tasks, their performance will depend on whether they can successfully apply metacognitive knowledge and skills to activating study strategies and tactics.

Veenman et al. (2006) have an insightful metaphor for the relation between metacognition and cognition: "If metacognition is conceived as (knowledge of) a set of self-instructions for regulating task performance, then cognition is the vehicle of those self-instructions. These cognitive activities in turn are subject to metacognition, for instance, to ongoing monitoring and evaluation processes" (p. 6). A basic inference from their view is that metacognition and cognition are operationally intertwined and it is hard to entirely disentangle them in assessments of metacognition. Metacognition is not always explicitly detected during cognitive activities. If so, people may argue how online metacognition can be validly assessed while cognitive processes operate. Like the issues

related to measuring SRL, this question poses considerable challenges. I will take up this issue in the section of SRL measurement.

Regarding the relationship between metacognition and cognition, it seems to be necessary to discuss the relation between consciousness and metacognition. This raises a fundamental argument about whether metacognition only refers to conscious and deliberate thinking processes versus embracing those automatic and unconscious, or at least tacit and habitual, metacognitive activities, such as automatic online monitoring and control of one's state of learning below consciousness. By definition, the concept of metacognition draws on the assumption that metacognitive processing is purposive, deliberate, and conscious. In other words, metacognitive functioning is assumed to involve conscious awareness of activities within the mind (Diana & Reder, 2004). Meanwhile, there are a number of studies showing that metacognition (e.g., monitoring of cognitive performance and strategy selection) is not always conscious (see Diana & Reder, 2004) or at least below full consciousness (Koriat, Bjork, Sheffer & Bar, 2004; Koriat, 2007).

Since "metacognition is a particular kind of cognition." (Nelson, 1999, p. 625) and given a trend in the learning sciences to research unconscious or implicit cognition (learning) (Kihlstrom, 1999; Litman & Reber, 2005), one may ask if there is a need to explore the conception of unconscious or implicit metacognition (Son & Kornell, 2005). Implicit learning is one of three major strands of research on which the emerging science of learning (or learning sciences) draws (Bransford et al., 2006). This issue will be further touched on in the section regarding the base of metacognition.

Main Issues in the Current Research on Metacognition

Metacognition has been researched along two lines that are relatively independent of each other: developmental psychology and experimental memory research (Koriat, 2007). The differences between these two traditions of research lie in goals and methodologies.

The line from developmental psychology was spurred by Flavell (1979) who argued for the critical role of metacognitive processes in developing memory functioning in the course of a child's cognitive development. Developmental accounts of metacognition assume that cognitive performance (learning and memory) largely depends on monitoring and regulatory proficiency. According to Koriat's summary (2007), the goal of this line of research is to specify the components of metacognitive abilities, to trace their development with experience, and to investigate the contributions of those components to memory functioning. The research is primarily descriptive and correlational.

The conception of metacognition in developmental psychology is more comprehensive than in experimental memory research. In contrast, according to Koriat, the experimental-cognitive study of metacognition aims at clarifying the mechanisms underlying monitoring and control processes in adult memory. Within-subject variation in metacognitive processes has been the focus of research in that line. The attempts along this line of research have yielded several theories and experimental paradigms for measuring the metacognitive monitoring and control processes occurring during and after learning.

Current research on metacognition is proceeding primarily along the line of the experimental memory research. According to Koriat (2007), five basic issues characterizing this school of metacognition research include: (1) What are the bases of metacognitive judgment in monitoring learning, remembering, and performance? (2) How valid are such judgments, and what the factors underlie the association between subjective and objective indexes of knowing? (3) What are the processes underlying the accuracy and inaccuracy of metacognitive judgment? (4) How does the output of metacognitive monitoring contribute to strategic regulation of learning and remembering? (5) How do metacognitive monitoring and control affect actual performance? Next, I will briefly review the literature regarding the first and the second question. The third and fifth questions will not be discussed because they are not relevant to this dissertation research. Since the fourth question regarding the relationship between metacognitive monitoring and control is the focal point in this dissertation research, it will be discussed in more detail in a separate section.

Main Types of Metacognitive Judgment

Metacognitive judgment is the core concept in the five main issues noted above. Thus, it is necessary to clarify the variety of metacognitive judgments and to briefly review the studies on the three main issues in metacognition research.

The output of monitoring is our judgment about products and processes that are monitored. For example, when a student monitors how well he or she has mastered an assigned task, the output of this monitoring could be a recognition that either he or she has learned it well or not well. That is his or her subjective judgment of the current state of learning.

Current research on metacognition primarily concerns three main types of metacognitive judgment (Koriat, 2007): *judgments of learning* (JOLs) elicited during learning, *feelings of knowing judgment* (FOK) elicited following a failed retrieval, and *confidence judgment* which is subjective confidence in the correctness of the answer retrieved from memory or after selecting an answer.

Simply, JOLs are people's subjective judgments about how well they have learned particular information in the learning material—that is, predictions about the likelihood that they will be able to remember the target item in the subsequent test (Son & Metcalfe, 2005). Accuracy of JOLs presumably influences strategy selection to control further study. Individual learners' calibration of cognitive performance (remembering) is measured by comparing the JOLs to their actual test performance.

In the paradigm of measuring FOK, participants are required to recall items from memory. When they fail to retrieve an answer, they are required to make a judgment about how likely they feel they could recall that answer later. After participants select an answer to each test question, they are asked to judge in the form of a probability the degree to which they believe their answers are correct. JOLs and FOK judgments are prospective because they are predictions of future cognitive performance. In contrast, confidence judgments are retrospective reflecting assessments about a memory that has been produced. This dissertation research only involves JOLs and confidence judgments. So, approaches to measuring JOLs and confidence judgment will be detailed in the chapter on methodology.

The Bases of Metacognitive Judgments

A critical question addressed in experimental research on metacognition is what metacognitive judgments are based on. Current research provides two views of metacognitive judgments: *direct-access* and *cue-utilization* (Koriat, 2007). First, the direct access view proposes that people have access to memory traces formed after learning. Their metacognitive judgments are based on detecting the presence and/or the strength of those traces. For example, JOLs elicited during learning are determined by the extent to which learners can detect memory traces. This account of metacognitive judgments assumes that a direct read-out of information from the study targets is involved in the monitoring process. That is to say, people can directly access the contents of their memories. If JOLs are based on accessing the strength of the memory trace formed during learning, they naturally should be predictive of future recall because recalling in the test also depends on access to that trace. In other words, both JOLs and subsequent recall share the same base. Thus, the direct-access view can explain why metacognitive judgments are accurately predictive of the actual performance.

In contrast, the cue-utilization view of metacognition is becoming more influential than the direct-access view in recent studies (Koriat, 1997; Koriat, 2007). According to this view, metacognitive judgments are inferential, based on a variety of cues and heuristics that are generally predictive of subsequent memory performance. The accuracy of judgments is not directly influenced by the strength of memory traces but the empirical correlation between cues used when a JOL is made and cues available during the criterion memory test. According to Koriat's summary (1997), these cues may include one's belief about his or her general memory efficacy, the conditions of learning, the type of memory test expected, previous task-specific experience, and the perceived relative

difficulty of the study items in question. This suggests that motivational variables such as self-efficacy belief, outcome expectation, as well as prior knowledge and previous experience in similar situations may play a role in forming people's online metacognitive judgments. Consequently, it can be inferred that it is useful to take learners' motivational beliefs (self-efficacy in particular) into consideration when looking into the bases and mechanisms of metacognition. Empirically investigating the role of motivation in exercising metacognition in SRL is the theme of this dissertation work. Further treatment of this goal will unfold in the later sections.

The aforementioned factors assumed to underlie metacognitive judgments can be categorized into three classes of cues: *intrinsic*, *extrinsic*, and *mnemonic* cues (Koriat, 1997). Concisely, intrinsic cues involve the inherent attributes of the studied items that give rise to the items' *a priori* ease or difficulty of learning. For example, research has found that both concrete words and common words are easier to process. Therefore, JOLs for these words are relatively higher than for abstract words (Begg, 1989, cited in Koriat & Levy-Sadot, 1999) because concrete words have higher recallability and are processed with greater fluency than abstract words.

Extrinsic cues refer either to the conditions of learning (e.g., number of times an item has been studied) or the encoding strategies used by the learner (e.g., level of processing). In contrast to the first two types of cues that affect JOLs directly through explicit application of a particular rule (e.g., trials for studying the targeted item), mnemonic cues are internal and subjective (Koriat). Mnemonic cues include the accessibility of pertinent information, the ease with which information comes to mind, cue familiarity, the ease of processing a presented item, memory about its ease of

acquisition, and memory about the outcome of previous recall attempts. It has been hypothesized that both intrinsic and extrinsic cues may affect JOLs directly, but they may also exert their effect indirectly through mnemonic cues.

According to Koriat (1997, 2007), the direct effects of intrinsic and extrinsic cues are likely to involve a logical and analytic process that draws on learners' beliefs, knowledge and theories, such as self-efficacy beliefs; and knowledge about themselves as learners (personal epistemology). In contrast, the internal and subjective mnemonic cues that involve a non-analytic, implicit inference use a global heuristic rather than a logical, conscious deduction to form JOLs. Therefore, the inferential, cue-utilization view of metacognition has been further decomposed into two sub-categories: *analytical, theory-based* (or information-based) and *non-analytical, experience-based* metacognitive judgments (Koriat & Levy-Sadot, 1999; Koriat, 2007).

In general, in a metacognitive monitoring process, analytical bases consciously and deliberately utilize one's beliefs and information (knowledge) to generate an informed judgment or guess about the state of learning whereas non-analytical bases implicitly apply some global, general heuristics to form a judgment (Koriat & Levy-Sadot, 1999). Those heuristics are believed to affect and shape people's subjective experience unconsciously and automatically.

Koriat and Levy-Sadot delineated the difference between information-based and experience-based metacognitive judgments along three dimensions: *mediation, content, and phenomenal quality*. This can help further identify distinct bases of these two types of judgments. First, in an information-based process, judgments primarily derive from the informational content stored in explicit memory rather than an affective reaction. In other

words, explicit cognition (beliefs and knowledge) consciously guides behavior. In contrast, an experience-based process that gives rise to an affective reaction is essentially implicit and unconscious. Second, the basis of the information-based judgments resides in domain-specific knowledge retrieved from memory. In the experience-based process, the information underlying judgment and feeling (e.g., feeling of knowing) is not or only partially available to consciousness. Third, in Koriat and Levy-Sadot's model, in the information-based process, people process information and behave in a controlled and deliberate manner; in contrast, the experience-based judgment is basically intuitive and automatic.

It is necessary to note that although in theory there is a sharp distinction between the analytic and non-analytic process underlying metacognitive judgments, they presumably work together in shaping metacognitive judgments (Koriat & Levy-Sadot, 1999). In my opinion, this distinction has elicited a question: Under which conditions and to what extent is measured metacognition non-analytical or analytical? For example, in the initial study of learning material, are learners' JOLs more experience-based (based on their previous subjective experience) than JOLs made when restudying the same material? Is online, real-time metacognition (e.g., study strategy selection and study time allocation) more non-analytical or data-driven than the offline retrospective, recalled regulation of cognition measured at the end of a learning process? These kinds of questions will be explored later based on data obtained in this study.

The Validity of Metacognitive Judgments

How valid are people's metacognitive judgments in assessing knowledge they actually have mastered? This is the second main research question that is currently

targeted by experimental metacognition researchers. It begs for clarifying the reason and conditions that affect the degree of correspondence between metacognitive judgments – subjective measures of knowing – and actual cognitive performance – objective measures of knowing.

Two measures used to quantify the validity of metacognitive judgments (the discrepancy between metacognitive judgments and actual performance in the test) have been widely used in the literature of SRL and cognitive psychology: *calibration* and *resolution* (Juslin, Olsson, & Winman, 1998; Stone, 2000; Winne & Jamieson-Noel, 2002; Koriat, 2007). Calibration research is a quite extensive area in psychology in close relation to SRL research (Stone, 2000; Winne & Jamieson-Noel, 2002) and experimental metacognition research (Koriat, Sheffer, & Ma'ayan, 2002; Kröner & Biermann, 2007). My focus will be limited to the calibration literature.

Calibration measures the absolute accuracy of metacognitive judgment by calculating the distance between an individual's mean of metacognitive judgments and mean actual cognitive (memory) performance on the judged items or tasks. It reflects the degree to which peoples' subjective judgments are valid (Stone, 2000). Technically, when the mean probability confidence judgment across the questions is c , and the percentage of correct answers is a , then the calibration is computed as $c-a$ (Soll, 1996). Positive calibration denotes overconfidence; negative calibration denotes underconfidence. Zero represents a perfect calibration. For example, if a participant reports an 80% level of response confidence averaged across questions, this person would be a perfect calibrator if his or her proportion correct for those question items is also 80%.

Otherwise, he or she would be either overconfident or underconfident in his or her achievement.

What factors influence people's calibration? According to Stone (2000), they include learners' individual characteristics, self-monitoring, feedback, and analysis method. Specifically, individual characteristics are composed of (a) level of confidence in one's ability or knowledge (i.e., self-concept), (b) level of expertise, and (c) inferential processes. For example, calibration research has found that people tend to be overconfident on hard tasks and underconfident on easy tasks (Metcalf, 1992, cited in Stone). Overconfidence is found to decrease as expertise grows (Pfeifer, 1994, cited in Stone).

The notion of inferential processes in the calibration literature essentially corresponds to the basic tenet in cognitive psychology that encoding and retrieval are constructive and reconstructive processes (Bruning, Schraw, Norby, & Ronning, 2004). The notion of inferential process suggests that reconstruction of information from the cues may provide an incomplete sense of knowing or of being able to know, leading to high confidence. As for the role of self-monitoring, according to Stone, there are two basic points: (a) self-monitoring generates internal feedback that affects the level of confidence, and (b) self-monitoring leads to better calibration only when it challenges one's capability or knowledge versus confirming performance. It is clear that feedback mediates the effect of self-monitoring on calibration.

Finally, numerous studies on how to improve the accuracy of JOLs have found that the time when metacognitive judgments are generated influences the level of confidence. Specifically, JOLs are found to more accurately predict future performance

when they are delayed after the study session than when judgments are made immediately (Nelson & Dunlosky, 1991; Thiede, Dunlosky, Griffin, & Wiley, 2005).

Recent research on individual differences in calibration explored the relationship between JOLs and the other psychological processes such as intelligence and self-concept (Kröner & Biermann, 2007). That study supported the significant finding from many previous studies that participants' response confidence is influenced by both self-concept and competence. This suggests confidence judgments are on the boundary between trait-likeness and competence. I will discuss this point in the discussion chapter by linking this theory to the empirical data obtained in the present study.

The Relation between Metacognitive Monitoring and Metacognitive Control

All of the five main research questions in the literature of experimental metacognition research reviewed in the last section are equivalently important to advancing knowledge about metacognition and its relations to other kinds of cognitive activities. The fourth question – the control function of metacognition – is central to this dissertation research it focuses on the nature of the relationship between metacognitive monitoring and metacognitive control, as well as the factors underlying this relation. Therefore, I now review existing models regarding this relation.

As stated previously, in Winne's model of SRL metacognitive monitoring and metacognitive control are viewed as the pivots on which self-regulated learning (SRL) turns (Butler & Winne, 1995; Winne, 2001). Winne's model highlights how important metacognitive monitoring and metacognitive control are and foregrounds their causal role in researching and understanding how SRL works. In other words, it is crucial for

understanding of SRL and how it can be productively applied in education to discern the mechanism of both metacognitive monitoring and metacognitive control, their relationship and factors underlying that relationship.

The basic assumption of this line of research is that subjective feeling and judgments play causal roles in human behavior (Koriat, 2007). In light of Nelson's two-level model of metacognition, monitoring elicited at the meta-level generates a subjective judgment about information at the object-level. The output of monitoring can guide the regulation of cognitive processes occurring at the object-level. Specifically, metacognition achieves control of cognitive activities by strategically regulating (Cary & Reder, 2002), for instance, the choice of which items to study and/or reread and allocations of study time to items in the learning material. Academically successful students are those who are knowledgeable of their study strategies and of how to apply those strategies appropriately under various specific circumstances (Son & Schwartz, 2002). Therefore, understanding students' regulation of reread appears to be very important to improve the efficiency and productivity of learning in educational practice.

The Discrepancy-Reduction Model – Simple Relation between Monitoring and Control

Dunlosky and Hertzog's discrepancy-reduction model (1998) is a widely recognized attempt to conceptualize the relation between metacognitive monitoring and control in learning (Koriat, 2007). The model emerged from the authors' attempt to build a theoretical framework of self-regulated learning in the area of metacognition research. Dunlosky and Hertzog's model is composed of three interrelated phases that reflect the temporal relation among metacognitive and cognitive activities occurring in a self-paced learning process where learners control their study pace within a given period of time.

The first phase is study preparation in which several interrelated metacognitive components are involved: memory self-efficacy evaluation, task appraisal and initial strategy selection. For example, learners' self-efficacy may affect their perception of task difficulty, as well as strategy selection. Task appraisal and strategy selection are informed by learners' general metacognitive knowledge about memory, rather than by fine-grained assessments of the current learning state at the preparation stage. In other words, at the initial stage of learning, both task appraisal and selection of strategy are preliminary, mainly based on prior knowledge and declarative metacognitive knowledge. That is congruent with the phase of task definition in Winne's SRL model. Two cognitive operations are involved during the second stage of ongoing study: (a) selecting individual units of information to learn and (b) monitoring the state of learning of those items. As an output of monitoring, a judgment is made about whether learning has achieved the desired goal called the "norm of study." If it has, study stops and then moves on to the third stage which is tests of newly studied material. The whole loop then starts again. If the item learned has not met the norm of study, study of that item will continue until it is achieved. Simply put, the discrepancy-reduction model tries to explain how people's metacognitive judgments of learning (JOLs) (an output of monitoring) guide their strategic allocation of time allocation and selection of items for study/restudy (i.e., metacognitive control).

Dunlosky and Hertzog (1998) claim that exercising learning strategies as metacognitive control involves two basic issues: (a) how learners spend their study time on content they are expected to master, and (b) when they stop study in the case of self-paced study. Dunlosky and Hertzog's discrepancy-reduction model has answered these

two questions. The answer to the first question is that the correlation between JOLs and the study time allocated is negative. Learners tend to spend less study time on items they judge easy to learn (high JOLs). The answer to the second question is that in the case of self-paced study learning continues until the perceived degree of learning equals or exceeds the norm of study. In this sense, the discrepancy-reduction model essentially concerns the relationship between monitoring and control in the so-called study-time-allocation paradigm (Son & Schwartz, 2002). In my opinion, this influential model in metacognition research essentially represents a linear and simple logic underlying how people's subjective judgment serves to control and regulate cognitive activities in learning – the greater the perceived difficulty of the information units, the more cognitive resources they receive (interpreted as attention paid to the units or study time).

Complex Relation between Monitoring and Control – The Focus of This Dissertation Research

Several studies have revealed that the relation between metacognitive judgment and control is always not as simple and linear as the discrepancy-reduction model predicts (Thiede & Dunlosky, 1999; Son & Metcalf, 2000; Dunlosky & Thiede, 2004; Son & Sethi, 2006). Those studies modified the discrepancy-reduction model by introducing the conditions under which learning unfolds. For example, Thiede and Dunlosky found that learners presented with an easy performance goal (e.g., to learn a list of 30 items but be tested on 10 of the 30 items) tended to select easier rather than more difficult items for restudy. This finding is significant because it essentially links learners' learning goal to their regulation of strategy use when learners are allowed to self regulate their cognitive activities, for instance, when they can freely choose study targets and control the pace of learning.

The above positive relation between JOLs and item selection, namely, that higher JOLs items are more likely to be chosen for study, is called the shift-to-easier-materials (STEM) effect (Dunlosky & Thiede, 2004). Dunlosky and Thiede investigated causes and constraints of the STEM effect on restudy time allocation. They found that, given a low performance goal, STEM effect appeared when learning items were presented for selection in a simultaneous format but disappeared when items were presented in a sequential format. They concluded that the presentation format qualitatively changed learners' pattern of regulating study time when they had a low performance goal. Their explanation was that when items were presented simultaneously, participants had time to plan how to allocate their limited time so they could meet the goal of the task while minimizing effort. In contrast, when items were presented sequentially the participants failed to plan or to execute the plan, if they had one, due to limited working memory capacity. This interpretation seems to indicate that people unconsciously or automatically tend to select difficult items and allocate more time to difficult items when they could not plan or execute a plan because planning requires awareness and consciousness which presumably involve motivation.

Son and Metcalfe's research (2000) also modified the logic of the discrepancy-reduction model. They found that learners under time pressure tended to allocate more study time to the items that they perceived as easy to learn or interesting rather than items perceived as difficult. Their hypothesis was that people's selective-attention may not be primarily guided by their assessments of the difficulty of the items but by people's interest or motivation. In other words, they hypothesized that people's control of study strategies may be not only guided by their cold assessment of how well they have learned

the targeted items, but also by the emotionally guided impulses such as interest. What are the implications of these findings for this dissertation research? In the next section, I will try to address this question.

The Specific Research Questions of This Dissertation Research

The research findings reviewed above converge on the point that study time allocation, a form of metacognitive control, is affected by factors other than JOLs. Factors such as learning goals (easy or difficult goals), time pressure, format of information presentation (sequential versus parallel), and task requirement (e.g., stressing accuracy versus quantity) also affect study time allocation. However, these factors are elements in the external environment within which learners' self-paced study takes place.

Research on metacognition has also suggested that the relation between monitoring and control is more complex than the discrepancy-reduction model describes. However, the research has not yet made clear whether learners' internal personal factors might affect the control function of metacognition. Current research on metacognition has not yet explored the possible role of people's motivational beliefs (e.g., goal orientations, self-efficacy beliefs), epistemological beliefs (e.g., attitudes toward simple knowledge, quick learning), metacognitive awareness (e.g., strategies of study monitoring), and other psychological processes. This dissertation expands the horizon of current metacognition research by exploring the role of those personal factors in fusing the relation between metacognitive monitoring and control in SRL processes.

There are essentially two specific hypotheses. One is that relations between monitoring and control in SRL are not as simple as the discrepancy-reduction model or even other updated models portray. This hypothesis can be tested by investigating the

complex relationship between learners' judgment of learning (JOLs) and their restudy time allocation. The second hypothesis is that the regulative function of JOLs with respect to study time allocation is affected by cognitive factors such as motivation, metacognitive awareness, epistemological beliefs, learning interest, and so on. Thus, self-regulated learners' accurate metacognitive judgments may not lead to appropriate metacognitive control because the relation between metacognitive monitoring and control is affected by learners' motivational and epistemological beliefs, metacognitive awareness, and other context-and subject-specific psychological processes.

Winne (2004) claimed that productive SRL will be proportional to metacognitive monitoring accuracy. This theory essentially suggests that as long as self-regulating learners are able to make accurate subjective judgments about their cognitive processes against standards, they will be able to choose appropriate learning strategies or study tactics to metacognitively control current learning toward a goal provided they have strategies/tactics in their long-term memory and the learning environment affords opportunity to exercise control. Simply, according to this reasoning, how people regulate and control their study strategies, such as selection of items and allocation to study time, is entirely a function of their metacognitive judgments. Does this thinking depict the whole picture of the reality? Does this theory fully fit into the empirical data obtained from the experiments? The following hypothetical situation can help us further understand the necessity of taking motivation variables into account when we explore how learners' personal factors may affect their exercise of metacognitive control.

Suppose after studying, Jeff predicts he will be able to answer 85% of multiple-choice questions on a final exam. This is his JOL. Meanwhile, he is aware this material is

quite interesting, even though not everything will be tested by the final exam. If Jeff has a performance orientation goal (i.e., to achieve a high grade), he is very likely to terminate studying at this point. Alternatively, if Jeff has a mastery orientation goal (to master what he is interested in), he is likely to continue to studying. So, with the same JOL, Jeff could be predicted to apply different metacognitive control (e.g., allocating study-time) as a function of his achievement goal orientation. In this sense, the effect of the JOL on his study time allocation is more complex than the discrepancy-reduction model predicts because it is influenced by his goal orientation.

In summary, the above analyses have identified motivational and epistemological beliefs as targets for enquiry. In the next sections, I will examine relations between motivation and cognition, and relations between personal epistemology and cognition in general and SRL in particular, to further strengthen the bases of this study.

Motivation and Its Relation with Metacognition

As stated earlier, both motivation and metacognition are regarded as essential elements of SRL, and many studies have investigated the role of the two components separately in forging productive SRL. The latest of these research achievements are collected in the book edited by Schunk and Zimmerman (2008).

The history of probing the relation between metacognition and SRL is almost as long as that of SRL research. However, inquiry about the relation between motivation and metacognition within SRL is less researched. It is too ambitious and unnecessary for this dissertation to exhaustively review all the research on the relation between motivation and SRL. The main objective of the following text is to answer these key questions: Why is it necessary to take motivation into account when we examine how

people's metacognitive judgments guide their study strategy use, specifically, selection of items to restudy and allocation of study time? Why is the relationship between metacognitive judgment and control not as the discrepancy-reduction model predicts? Why is that relation presumably affected by motivation? Why do the learners generally allocate more time to items well learned when they are allowed to control their study time? Providing answers to these questions is not easy but the attempt to theoretically and empirically associate motivation with metacognition might be the most valuable and most core part of this dissertation research. The essence of those questions, in my view, centers on whether learners' online allocation of cognitive resource (i.e., attention) is motivated behavior.

To answer these questions, I will briefly review current studies about the role of motivation in SRL in general. Then, I will come back to the core issue, why it is necessary to explore how motivation influences the regulation of cognition such as allocating restudy time which is examined in this study. First, I examine the definition of motivation and main theories of motivation in educational psychology.

Definitions of Motivation

Finding a general statement about motivation in textbooks about educational psychology is not difficult, but theorizing what this concept refers to is not straightforward. Motivation is regarded as a multi-faceted construct and researchers with different theoretical traditions tend to choose slightly different definitions or prefer different aspects of the concept of motivation. As an important concept in scientific research of human cognition and behavior, motivation may be understandable only within a general theoretical framework.

From a cognitive perspective, Schunk, Printich, and Meece (2008) offer a general definition of motivation: “Motivation is the process whereby goal-directed activity is instigated and sustained.” (p. 4). There are several key points embedded in this definition. According to Schunk et al., first, motivation refers to a mental process rather than a state or product. Thus, it cannot be observed directly but rather must be inferred from its products – behaviors such as choice of task, effort, and so on. In this sense, motivation is internal and inferential in nature. Second, motivation is inherently related to goals that provide impetus for action. Cognitive views of motivation emphasize the importance of goals which more or less require awareness and consciousness. Third, motivation can be expressed as either physical or mental activity. Physical activities involve effort, persistence, and so on. Mental activities entail cognitive operations such as encoding, retrieving, planning, monitoring, solving problems, and so on. Finally, motivation leads to initiating and sustaining activities.

Although cognitive views of motivation converge on the importance of cognitive elements, they disagree about which processes are prime (Schunk et al., 2008). Therefore, under the umbrella of the cognitive tradition, different emphases on elements such as task value, attributions, efficacious beliefs, goals and goal orientation, intrinsic needs and drives, and social comparison, has led to different models of motivation. The theories that conceptualize these processes include: expectancy-value theory, attribution theory, social cognitive theory, achievement goal orientation theory, and self-determination theory (SDT). This corroborates the view that motivation is multi-faceted and composed of a number of constructs. In what follows, I will present those key motivational constructs and their relation with learning.

Role of Key Components of Motivation in SRL

Zimmerman and Schunk (2008) synthesized a number of motivational variables in the framework of SRL. I will only review key components of motivation that are relevant to this study – self-efficacy, goal orientations, task value, and intrinsic/extrinsic motivation – and attempt to link these with metacognition. For example, how do goal orientations influence our regulation of cognitive processes?

Self-Efficacy Beliefs – Core Element of Social Cognitive Theory of Motivation

In Bandura's social cognitive theory, motivation is regarded as goal-directed behavior initiated and sustained by self-efficacy beliefs and outcome expectations (Schunk et al., 2008). Outcome expectations are what people expect of their actions.

As a core construct in social cognitive theory, Bandura's definition of self-efficacy is most authoritative. Self-efficacy beliefs are "people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances" (Bandura, 1986, p. 391). The importance of self efficacy can be seen from the statement that it is the foundation of human agency and plays a pivotal role in the causal structure of social cognitive theory, as well as in the self-regulation of motivation (Bandura, 2001). Unlike self-concept which reflects a general cognitive representation of competence, self-efficacy beliefs are specific and situational judgments of particular personal capabilities (Linnenbrink & Pintrich, 2003; Woolfolk, Winne, & Perry, 2005). Thus, presumably efficacy beliefs are a kind of self-judgment and, therefore, it be hypothesized that self-efficacy beliefs essentially involve or arise from metacognitive judgments that yield a subjective assessment of whether one is able to accomplish a specific task.

Explicitly linking self-efficacy to metacognitive judgment is rarely found in the literatures of motivation and metacognition. Since self-efficacy belief as a situationally dependent construct, it is often measured after learners are informed of content to be learned but before they begin to study. Thus, can it be hypothesized that a subject-specific self-efficacy belief is shaped alongside the processes of task definition in SRL (Winne, 2001) and forming ease of learning (EOL) judgments at the beginning of study? This question concerns a very important issue, whether self-efficacy beliefs are an event-like or a trait-like construct. This point is similar to the idea that self-efficacy beliefs as judgments elicited in similar tasks may vary as a function of intra-individual or environmental differences (Linnenbrink & Pintrich, 2003).

Linnenbrink and Pintrich (2003) summarized that self-efficacy beliefs impact three aspects of engagement in learning: *behavioral engagement*, *cognitive engagement*, and *motivational engagement*. Behavioral engagement corresponds to the notion of physical activities introduced previously as one of the two expressions of motivation (Schunk et al., 2008). Specifically, students' behavioral engagements in learning processes take form in effort, persistence, help seeking, and so on (Linnenbrink & Pintrich, 2003). In general, students with strong self-efficacy beliefs are not only more willing to spend more effort in the face of difficulty and to persist at tasks, but more likely to seek adaptive and instrumental help in the classroom. That is to say that self-efficacy beliefs influence learners' metacognitive regulation of study time expenditure. Therefore, can we hypothesize that self-efficacy beliefs are factors underlying metacognitive control behavior as well? It seems that we have one more reason to ask if the relation between metacognitive judgment and control is affected by motivation. Or, is

self-efficacy as a subjective judgment of one's task-specific capabilities a kind of metacognitive judgment on its own? In other words, presumably the formation of self-efficacy beliefs involves or embraces an ingredient of metacognitive judgment. In this sense, both self-efficacy beliefs and metacognitive judgment intertwine with one another.

If behavioral engagement only concerns so called "hands on" activities, cognitive engagement involves "mind on" actions in cognitive processes (Linnenbrink & Pintrich, 2003). Many studies corroborate the conclusion that the relation between self-efficacy and students' active use of cognitive and metacognitive strategies is positive for cognitive engagement. Specifically, high self-efficacy beliefs are positively correlated with the use of deep processing strategies, such as elaborating, organizing, planning, self-monitoring and controlling one's cognitive processes. Students with high self-efficacy beliefs monitor their study resources (e.g., time) effectively (Pajares, 2008). Again, this suggests that students' regulation of cognitive processes (metacognitive control) is affected by their self-efficacy. In terms of motivational engagement, self-efficacy beliefs are positively related to other motivational variables such as interest and task value (Linnenbrink & Pintrich, 2003). Self-efficacy beliefs influence achievement motivation through the use of self-regulatory processes such as goal setting, self-monitoring, and strategy use (e.g., study time allocation).

Goal Orientations

Research on achievement goal orientation theory is currently one of the most active areas of research reflecting a social cognitive view (Pintrich, Conle, & Kempler, 2003). Goal orientations concern the purposes for engaging in cognitive behaviors (Schunk et al., 2008) (e.g., "I wrote a summary for each chapter because I wanted a high

grade.” or “I am pretty interested in this topic.”). Goal orientation not only refers to the purpose or reason for engagement, but reflects a kind of standard by which learners judge the success or failure of their cognitive engagement (Schunk et al. 2008,). Thus, this concept concerns a way in which learners define and evaluate the value of what they do in learning. What does this idea imply in terms of metacognition? As noted before, regulation of cognitive processes such as allocation of study time essentially concerns people’s selective attention. Thus, can we ask if goal orientations serve as standards in guiding selective attention? Does that mean goal orientation intertwines with metacognitive processes? If yes, this reflects a link between motivation and metacognition. In other words, it is theoretically necessary to take goal orientation into account to understand metacognitive processes.

Two main types of goal orientation are pervasive in the literature of motivation: *mastery goal orientation* and *performance goal orientation*. In the history of goal orientation theories, these two types of goal orientation are termed differently. For example, mastery goal orientation has been referred to as task-involved (Woolfolk et al., 2005) or intrinsic goal orientation (Duncan & McKeachie, 2005); performance goal orientation is also known as ego-involved or extrinsic goal orientation. Although a 2 X 2 achievement goal framework comprising mastery-approach, mastery-avoidance, performance approach, and performance-avoidance goals has been widely adopted in recent work on motivation (Elliot & McGregor, 2001), this dissertation focuses on the approach form of motivation, namely, mastery-approach and performance approach. According to Schunk et al. (2008), a mastery goal orientation generally refers to a tendency to learn and to master the task according to intrinsic desires for self-

improvement. It is grounded in the internal need or drive for achievement (Elliot, McGregor, & Gable, 1999). Thus, mastery goal orientation is intrinsically orientated in nature. In contrast, a performance goal orientation represents a focus on displaying competence and how personal ability will be judged compared to others. It is extrinsically oriented.

Mastery goal orientation positively predicts deep processing, persistence, and effort expenditure during studying (Elliot et al., 1999). In terms of SRL processes, mastery goal orientation is associated with self-monitoring and active use of deep processing strategies (Zimmerman & Schunk, 2008).

Intrinsic and Extrinsic Motivation – Self-Determination Theory of Motivation

Pintrich in his influential, comprehensive article on motivational science (2003) pointed out that in current research on motivation, self-determination theory is an integration of the needs and social-cognitive constructs of motivation such as self-efficacy and perceived competence. Motivational constructs in social cognitive theory operate at an explicit and conscious level.

In contrast, self-determination theory (SDT) emphasizes implicit and unconscious processes of motivation. SDT assumes that people have a natural tendency to actively engage in the environment to absorb new knowledge and skills, and to integrate them into a coherent cognitive structure (Ryan, Deci, & Jang, 2008). The SDT model proposes that individuals have three basic innate psychological needs: *competence*, *autonomy*, and *relatedness* (Ryan & Deci, 2000). Simply, the need for competence refers to a desire to be capable and to master tasks. The need for autonomy refers to a sense of control over or self-determining of one's behavior. The need for relatedness reflects an inherent tendency

to belong to a social group. Ryan and Deci claimed that “The construct of intrinsic motivation describes this natural inclination toward assimilation, mastery, spontaneous interest, and exploration...” (p. 70). Intrinsically motivated people engage in an activity because they find it innately interesting and enjoyable. In contrast, extrinsic motivation leads people to engage in an activity as a mean to attain some separate outcome such as a reward or avoidance of punishment.

A fundamental tenet in SDT is that intrinsic motivation corresponds to the proactive, growth-oriented nature of human beings (Ryan & Deci, 2000). Indeed, intrinsically motivated activity is the natural basis for learning and development. According to Schunk et al. (2008), intrinsic motivation and extrinsic motivation are not the two ends of a continuum. It is more accurate to theorize them as separate continuums. In other words, there is no intrinsic relation between them – one may be high or low on both intrinsic and extrinsic motivation simultaneously for any given task.

A widely accepted conclusion is that intrinsic motivation fuels active engagement and learning because interest is accompanied by enjoyment (Ryan et al., 2008). In terms of SRL, intrinsic motivation as opposed to extrinsic motivation brings about autonomous self-regulation which refers to regulation of cognition and behavior that stems from people’s innate needs and values for engaging in learning. In this sense, intrinsic motivation is a construct similar to the concept of mastery goal orientation although the latter involves more cognitive and conscious processes.

Motivated Thinking – The Interface between Motivation and Cognition

The focus of the preceding sections was on establishing a theoretical basis to introduce motivational variables into the relation between metacognitive judgment and

control. The central idea is that, besides people's metacognitive judgment, motivational beliefs influence how they regulate and control cognitive processes, specifically in the current study, how they allocate study time and select items for restudy. The above literature review has touched this core issue by initially and hypothetically relating motivation to the mechanism of judgment and regulation of study strategies. However, an empirical connection between them has not been completely established. In this section, I review research on the general relation between motivation and human cognition as well as effects of people's motivated thinking on cognitive processes, judgment and decision making (Kruglanski, 1999; Higgins, & Molden, 2003; Higgins & Spiegel, 2004; Molden & Higgins, 2005; De Dreu, Nijstad, & van Knippenberg, 2008). The central idea is that motivation affects how people arrive at particular conclusions and whether they adopt particular strategies in reaching judgments (Higgins & Spiegel, 2004).

The history of research on motivational perspectives on thinking and reasoning can date back to Freud (Molden & Higgins, 2005). Research on the influence of motivation on judgment reappeared in social psychology in 1990s after prior debates about whether people's judgments stem from motivation or cognitive processes had abated in the 1960s and 1970s (Higgins & Molden, 2003). It must be pointed out that the theories to be introduced about the motivation-cognition interface in making judgments and decisions were investigated using paradigms and situations adopted for research in social psychology. I realize caution is necessary when applying that research to conceptualize the motivation-cognition interface in students' SRL processes. However, it will be seen that an analogy between them seems reasonable and useful.

First, I reviewed recent work on motivated thinking (cognition) by Molden and Higgins (2005) and research on motivated behavior. For example, attending to some information items in a reading task is a cognitive behavior that is presumably guided explicitly or implicitly by individuals' motivation, including selective attention or motivated gaze (Isaacowitz, 2006). These areas can be related to advances in cognitive neuroscience (Brown, 2007).

According to Molden and Higgins (2005), motivated thinking is the interface between motivation and cognition. They categorize two ways that motivation affects people's judgment and decision processes: *outcome-motivated thinking* and *strategy-motivated thinking*. Each categorization of motivated thinking involves a different mechanism of judgment and decision formation. Since metacognitive control concerns strategy selection and use, regulation of cognitive processes is relevant to decision making. As a result, it can be assumed that exploring the relation of motivation with metacognitive control in essence means exploring the effect of motivated thinking on decision making about how students allocate study time to learn. Motivated thinking in this sense conflates motivation with cognition and reasoning.

Outcome-Motivated Thinking

Research on outcome-motivated thinking is trying to figure out how people's goals, needs, and preferences influence their thought process (Molden & Higgins, 2005). Specifically, the basic tenet is that people's preferred outcomes (goals) influence their thinking and reasoning processes by directing cognitive processes such as attributing, recalling, searching for information, and evaluating.

According to Molden and Higgins (2005), first, the effects of motivation on reasoning are manifested as an influence on people's attribution. For example, research found that the more personally important a success is in a given circumstances, the more willing people are to take responsibility for that success but to deny responsibility for failure (Miller, 1976, as cited in Molden & Higgins, 2005). Does this have implications for hypothesizing motivational effects on people's retrospective self-reports about their cognitive and metacognitive processes in the end of a learning process? For example, when participants are asked to recall how they used learning strategies (e.g., study time allocation) at the end of an experiment, will their recalled strategy use be influenced by their goals, outcome expectation, task value, self-efficacy beliefs?

Second, motivation for positive self-evaluation influences how people evaluate information related to self-evaluation. Specifically, people give more credence to the validity of information that supports or confirms their desires.

Third, motivation is not only found to impact qualities of people's information processing while thinking and reasoning, but also the quantity and speed of information processing and search. Motivation for positive outcomes leads to quick termination of information processing and quick acceptance of favorable information. In contrast, people have a tendency to increase processing and hesitate to accept unfavorable information. This stimulates thinking about how people reading a text might differentially process information they judge difficult or easy to understand.

In summary, these and similar studies support the idea that people's outcome-based motivation does affect their thinking and reasoning through (a) the explanation (attribution) of events and behaviors; (b) the organization, recall, and activation of

knowledge; and, (c) the evaluation of evidence relevant to decision making (Molden & Higgins, 2005). The basic principle is that people's motivation to achieve goals can significantly change their cognitive processing in forming judgments (Higgins & Molden, 2003).

Strategy-Motivated Thinking

People not only have preferred judgment outcomes, they also have preferred judgment strategies to reach those outcomes (Higgins & Spiegel, 2004). Preferred strategies are ones that allow people to sustain their current motivation orientation. Such strategic motivation is measured in terms of people's regulatory focus. Two types are distinguished: promotion focus and prevention focus.

According to Molden and Higgins (2005), a promotion focus concerns advancement and approaching attainment whereas a prevention focus concerns security and ensuring non-losses. In light of goal orientation theory, the promotion focus contains elements of both mastery and performance approaches whereas the prevention focus aligns to mastery and performance avoidance (Elliot & McGregor, 2001). In the theory of strategy-motivated cognition, a promotion focus leads to preferences for quick judgment strategies that stress advancement. In contrast, a prevention focus results in preferences for vigilant judgment strategies that stress protection (i.e., making correct rejection).

Research has revealed that both types of strategic motivation have effects on aspects of cognition. For example, strategy-based motivation influences preferences for either speed or accuracy in one's thinking and decision making (Molden & Higgins, 2005). Specifically, a promotion preference for eager strategy elicits faster information

processing whereas a prevention preference for vigilant strategies results in more accurate information processing.

These and other studies provide strong evidence that motivation and cognition interact through two types of thinking: outcome-based and strategy-based. Both people's motivation for particular outcomes and motivation for particular preferred strategies affect their judgmental and decision processes (Higgins & Spiegel, 2004). This is a very important conclusion justifying investigating the role of motivation in influencing learners' metacognitive processes.

Motivated Behavior and Selective Attention

The preceding section provided an overview of recent studies regarding the interface of motivation and cognition – motivated thinking or cognition that primarily is concerned with the association between these two mental processes or cognitive processes. In social cognitive theory, motivation involves a goal-directed cognitive process and is a form of cognition rather than an innate need or drive. In this sense, motivation and cognition presumably intertwine with and are inseparable from one another. In educational psychology, cognition usually refers to mental processes concerning activation, acquisition, and development of knowledge – academic cognition which includes cognitive operations such as attention, reasoning, and problem solving (Pintrich, 2003). According to Pintrich, we know little about the link between motivation and these knowledge-based models of cognition.

Thus, in this section, I take a different perspective to explore the relation between motivation and cognition (or learning) by examining the effects of motivational factors being researched in the emerging cognitive neuroscience, namely, motivated behavior

and attentional selection. Attention is a critical cognitive resource necessary for learning (Brunning et al., 2004).

As one of the two components of metacognition, metacognitive control primarily concerns regulation of cognitive resources by selecting study strategies, selecting information units, and allocating attention (i.e., study time) to targeted items while studying. Exploring the patterns of learners' regulation of cognition in a reading task consequently entails delineating the profile of their attentional processes during study. This matter has been studied as using research paradigms adopted in the field of cognitive neuroscience such as brain imaging (e.g., fMRI – functional Magnetic Resonance Imaging) or gaze tracking (Parkhurst, 2002; Isaacowitz, 2006; Balcetis & Dunning, 2006; Wright & Wiediger, 2007).

According to Rueda et al. (2007), implementing desired actions (goals) requires orienting attention to selected objects in the environment that are instrumental for approaching the goals. It has been widely accepted that the human attentional system influences information processing and plays an important regulatory role in individuals' interactions with the environment. This is not only a conclusion of theoretical analyses but is supported by empirical findings generated by means of fMRI and cellular recording. Those studies demonstrated that a number of brain areas play a vital role not only in modulating activity within visual systems while attentional selection occurring, but also in processing the semantics of words and encoding and storing information in memory. A basic conclusion from these empirical studies in cognitive neuroscience is that “Attention can be automatically driven by external stimulation or endogenously controlled in accordance with the goals and wishes of the individual.” (Rueda et al., p. 30)

In the context of examining relations between motivation and attentional selection using patterns of eye movements (Parkhurst et al., 2002; Isaacowitz, 2006), a key need is clarifying the relation between selective attentions and fixations of a participant's eye gaze in the reading tasks. A basic tenet underlying their research is that attentional mechanisms and a person's neural architecture determine which incoming visual information is or is not selected and fully processed. The experiments researching these two mechanisms share a common assumption that eye movements and attention are associated.

Parkhurst et al. (2002) made a distinction between two major attentional mechanisms that control this selection process: bottom-up *attentional selection* and *top-down attentional selection*. Bottom-up attention selection is fast, automatic, and stimulus-driven, and primarily determined by the visual features of the environmental stimuli as well as the innate architecture and neural mechanisms of the primate visual cortex. In contrast, top-down attentional selection is slow, conscious, and goal-directed such that the gazer's expectations or intentions influence the allocation of attention through the semantic feature of stimuli. Although one may argue that the locations of attention and the fixation of eye gaze can be dissociated, "psychophysical evidence indicates that focal attention at the location of a pending eye movement is a necessary precursor for that movement." (Parkhurst et al., 2002, p. 108). That is to say, that gazing at a location is necessary but not sufficient for selectively attending to that location. In these studies, gaze to refer to where an individual fixates and that location can be called the target of visual attention (Isaacowitz, 2006). In many cases, it is believed that both eye movements

and attention can serve the same goal, selecting the instantaneously most important parts of the visual input.

A number of empirical eye tracking experiments conducted in Isaacowitz's lab (2006) have found that gaze is tied to gazers' psychological properties. For example, researchers in Isaacowitz's lab compared the patterns of gaze between two groups of childless women when they looked at the images of babies. In one group, the female participants had not yet passed the age for childbearing whereas in another group the participants had. They found that post-threshold participants shifted their gaze from babies faster than did pre-deadline women while both groups did not behave differently in gaze toward non-baby stimuli. They inferred that for pre-threshold women, images of babies served as goal-relevant stimuli; for post-threshold women, those images were goal-irrelevant. Thus, their conclusion was that gaze appeared to be closely tied to goal orientation supporting the idea that gaze can reflect general motivational processes. The limitation of this conclusion, in my opinion, is that participants' goals (expecting to bear children or not) should also have been measured by self-report rather than simply by researchers' inference. This remark accords with Winne and Perry's (2000) recommendations that trace measures should be accompanied by self report data to bolster interpretations about learners' cognition. Many similar empirical studies found that motivated gaze treated as selective attention rules out goal-irrelevant stimuli from prior to processing (Isaacowitz, 2006). In this sense, gaze can be a general tool of motivation and goal-directed behavior.

Motivated Reasoning and Perception

As introduced earlier, top-down selection implies that our visual perception and attention can be a goal-directed and motivation-driven process (Balcetis & Dunning, 2006). That means that what we see, to a large extent, is what we want to see. According to Balcetis and Dunning, we can not abide our traditional view of the world where “what people see or hear is an exact replica of what is out in the world” (p. 612). They made two inferences from this premise. First, perception is biased. Second, perception is malleable. That suggests that top-down influences on people’s visual perception originate from their cognitive and psychological states.

In a series of experiments, Balcetis and Dunning (2006) examined how people’s perceptions of the outside world were guided by participants’ personal motivational states such as wishes and preferences. For example, they found that participants tended to interpret an ambiguous figure in a way that fit their wishes and preferences. Balcetis and Dunning’s empirical studies, alongside others investigating motivated reasoning’s influence on people’s cognitive processes, support the idea that motivated reasoning influences conscious, deliberate, and effortful judgments.

In conclusion, many empirical studies have revealed the innate relation between human motivation and behaviors at the level of brain activity and eye movements. This grounds knowledge about the effects of motivation on people’s cognitive processes on a scientifically solid foundation. Those studies also showed that people’s attentional selection in information processing activities (e.g., reading) can be measured by eye gaze data. This methodology was adopted in this dissertation research to assess learners’ allocation of study time while reading a text.

Thus far, the sections support the idea that motivation plays a key role in higher-order cognition, thinking, as well as in lower-order observable behaviors. The details of how these findings can be used will be introduced in the methodology chapter. This topic will be also discussed later regarding the challenges of measuring SRL.

The Effects of Epistemological Beliefs on Metacognition

Besides motivational variables, learners' personal epistemology – their beliefs about the nature and sources of human knowledge and knowing – is another factor that will be probed regarding the relation between metacognitive judgment and control in SRL. Many educational psychology studies have found that learners' individual differences in personal epistemology directly or indirectly influence their cognitive engagement (DeBacker & Crowson, 2006). In this section, I will not carry out a systematic and exhaustive literature review of all of the aspects of the multidimensional framework of epistemological beliefs. Rather, I primarily focus on the models of how these beliefs are a part of and influence cognitive, motivational processes and, in particular, metacognition.

This section is composed of three sub-sections. First, I outline the main models describing the nature and content of epistemological beliefs. Second, I review key research regarding general relations of personal epistemology to SRL. Based on these sub-sections, a third section will focus primarily on how epistemological beliefs influence learners' use of learning strategies, one of the central issues addressed in the present study regarding whether and how metacognitive control study, operationalized as time allocation, is affected by individual's epistemological beliefs.

Definition and Components of the Epistemological Beliefs Construct

As a branch of philosophy, *epistemology* generally concerns the origin, nature, limits, methods, and justification of human knowledge (Hofer, 2002, 2004). From a psychological and educational perspective, personal epistemology refers to individuals' personal "beliefs about the definition of knowledge, how knowledge is constructed, how knowledge is evaluated, where knowledge resides, and how knowing occurs" (Hofer, 2002, p. 4). The concept of epistemological beliefs is generally exchangeable with others such as personal epistemology, epistemic beliefs, and epistemic cognition. These terms in the field of educational psychology are viewed in a psychological and educational light rather than a purely philosophical one because of educational psychology's interest to investigate how people's beliefs about knowledge and knowing influence and are influenced by learning and education (Hofer, 2004). For instance, the models of epistemological development by developmental psychologists share a central assumption regarding the nature of personal epistemology, which is that personal epistemology can best be recognized as an evolving construct that comprises several coherent and integrated representations (Hofer, 2004). The development of personal epistemology is the part of a stage of cognitive development, which can be traced back to Piaget's notion of "genetic epistemology" (Hofer, 2002).

Schommer (1990) and Hofer and Pintrich (1997) established multidimensional frameworks of personal epistemology whose central tenet is that the multiple dimensions of personal epistemology are relatively independent from one another. This contrasts with developmental frameworks in which those components of progressive personal epistemology are organized as a whole and develop in a unified way from an absolutist-

dualist to relativist-multiplist worldview (Hofer, 2008). Notably, there is debate about the degree of coherence among those dimensions (Hofer, 2004).

By and large, research in personal epistemology over the past decades has attempted to solve two main problems (Schraw, Bendixen, & Dunkle, 2002). One is identifying an exhaustive but concise set of epistemological beliefs, namely, conceptualizing facets of this construct. The other is developing a reliable and valid measure of these beliefs, namely, operationalizing this construct.

Schommer's multidimensional framework (1990) categorizes five beliefs of personal epistemology – beliefs about the certainty, simplicity, sources of knowledge, the speed, and control of knowledge acquisition. The first two dimensions concern the nature of knowledge (Bråten, 2008). Specifically, beliefs about the certainty of knowledge answer the question about whether knowledge is absolute and static or tentative and dynamic. Beliefs about simple knowledge refer concern whether knowledge is a set of isolated facts or innately coherent concepts. The last three dimensions involve the second aspect of epistemological beliefs, the nature of knowing (Bråten, 2008). The dimension of source of knowledge, also known as omniscient authority, concerns whether knowledge resides in external authority or is actively constructed by learners themselves. The dimension of speed of knowledge acquisition is about whether learning can occur quickly or gradually as a result of effort. Last, control of knowledge acquisition refers to beliefs about whether the ability to learn is fixed or malleable. Measures of participants' epistemological beliefs in the present study included these five dimensions.

General Relations between Epistemological Beliefs and Learning in Academic Settings

Theoretical explorations and empirical studies have revealed that epistemological beliefs influence strategy use, comprehension, cognitive processing, and conceptual change (Hofer, 2008). To model relationships between epistemological beliefs and metacognition, the emphasis in this sub-section will be on how epistemological beliefs influence learners' regulation of learning strategy and self-regulatory cognitive processing.

Bråten and Strømsø (2006) investigated whether learners' beliefs about the speed of knowledge acquisition influence their self-reports about cognitive processing and text-processing strategy in Internet-based searching activities. Their correlational study generated three conclusions. First, students who believed that learning occurs quickly were more likely to consider search for and evaluation of information unproblematic compared to students who believed learning is a gradual process requiring time and effort. Second, students holding beliefs that knowledge is fixed and static were less likely to engage in discussion and communication about content found on the Internet. Third, students who believed that knowledge is fixed and static reported they adopted surface text processing strategies. In short, epistemological beliefs influenced the degree of students' reported cognitive engagement concerning effort and types of learning strategies used (Ravindran, Greene, & Debacker, 2005).

Dahl, Bals, and Turi (2005) found that the dimensions of epistemological beliefs concerning the simplicity and stability of knowledge have the greatest relationship with learners' self-reported selections of cognitive and metacognitive strategies. Specifically, students who believed knowledge is isolated tended to report using rehearsal strategies;

otherwise, they tended to use organization strategies to connect information. Second, students who believed knowledge is malleable tended to report using elaboration and critical thinking strategies. More importantly, these researchers found that the more students believe knowledge is simple and fixed, the less likely they are to report using metacognitive and self-regulation strategies such as planning and monitoring.

Ravindran et al. (2005) also found that students tended to adopt shallow processing strategies when they believe the structure of knowledge is simple, the content of knowledge is certain, and knowledge can be acquired quickly from omniscient authorities if one has sufficient innate capacity to learn. In contrast, students who did not believe in omniscient authority tended to report using deep-processing strategies and self-regulation.

While the literature provides evidence showing epistemological beliefs and learning strategies are closely linked, there is a need for more research to address this association (Moschner, Anschuetz, Wernke, & Wagener, 2008). Muis (2007) provided an informative summary relative to the relationship between epistemological beliefs and the use of learning strategy in mathematics tasks. Generally, the more students held naïve epistemological beliefs, the more likely they were engage in surface-level strategies such as rote memorization and rehearsal strategies, which may subsequently lead to lower performance. The more students reported adopted constructivist epistemic beliefs, the more likely they reported using deep-level strategies, such as elaboration and integration of information which may subsequently lead to higher performance.

Because learners' epistemological beliefs interact with their selection of learning strategies, it follows that relationships between personal epistemology and metacognitive and self-regulatory processes should be examined.

Personal Epistemology as Metacognitive Processes

As mature life-long learners, each of us makes judgments and choices when we experience cognitive conflict between what we have believed correct and what authorities, such as teachers and textbook authors, tell us. Who is correct, whose "version" of information do we accept, and why? According to Hofer (2004), epistemic monitoring of and judgments about learning occur throughout school and in other arenas of our life.

Hofer (2004) conceptualizes personal epistemology as a metacognitive process called *epistemic metacognition*. She drew on Kitchener's (1983) view of personal epistemology as an interaction among cognition, metacognition, and epistemic cognition, which involves judgments about the limits and certainty of knowing that influence the epistemic nature of problem solving. She also borrowed from Kuhn's theory (1999) that distinguished (a) declarative knowledge about knowing, or metacognitive knowing, from (b) procedural knowledge about coming to know, or metastrategic knowing, from (c) general knowing about the self and others, termed epistemological meta-knowing.

The key to Hofer's model of epistemic metacognition (2004) is locating epistemological beliefs within a model of metacognition by comparing and contrasting the existing three-dimension model of metacognition with the five-dimension model of personal epistemology. Pintrich, Wolters, and Baxter (2000) categorized three components of metacognition: metacognitive knowledge, metacognitive monitoring, and regulation and control of cognition and learning. Hofer expands metacognitive

knowledge to the two dimensions of personal epistemology: certainty of knowledge and simplicity of knowledge. By definition, metacognitive knowledge refers to knowledge of learning strategies, tasks, and the self as learner.

This literature review has shown that our beliefs about certainty and simplicity of knowledge – beliefs about the *nature of knowledge* – have some correlation with strategy use (Dahl et al., 2005; Ravindran, et al., 2005). The second comparison is made between metacognitive judgment and the other two dimensions of personal epistemology: beliefs about source of knowledge plus the justification of knowledge, and beliefs about the nature of knowing. Evaluating the source of knowledge (e.g., asking how information fits into my own experience) and determining a justification or knowledge (e.g., asking if there is evidence to support this claim) by nature involve a process of monitoring and making judgment. Thus, Hofer argues that they can be analogous to metacognitive monitoring and judgment. A fifth dimension of personal epistemology is the control of knowledge acquisition that refers to the beliefs that one's ability to learn is fixed or malleable. That corresponds to a third component of metacognition: self-regulation and control of cognition. As Hofer pointed out, further investigations are needed to look into the metacognitive nature of those dimensions of epistemological beliefs by using various effective methodologies beyond the think-aloud method used in a set of empirical studies by Hofer and her colleagues.

An Integrated Model Connecting Epistemic Beliefs to SRL

Systematic research on integrating epistemic beliefs into SRL models is rare (Muis, 2007). In response to “Pintrich’s (2002) call to advance theoretical specifications of relations between epistemic beliefs and self-regulated learning” (p. 174), Muis

proposed an integrated model connecting epistemic beliefs and SRL by extending previous models of personal epistemology. Four propositions constitute the framework of her model: “(a) epistemic beliefs are one component of the cognitive and affective conditions of a task, (b) epistemic beliefs influence the standards students set when goals are produced, (c) epistemic beliefs translate into epistemological standards that serve as inputs to metacognition, and (d) self-regulated learning may play a role in the development of epistemic beliefs.” (p. 174)

Muis’s model (2007) is built on the assumption that epistemic beliefs play a role in each of the four phases of Winne and Hadwin’s self-regulated learning process: task definition, planning and goal setting, enactment, and evaluation (Winne & Hadwin, 1998). According to Muis, two actions comprise task definition: task analysis and self-motivation. Task analysis leads to goal setting and strategic planning; self-motivation results from activating beliefs about learning, including motivational beliefs and epistemological beliefs. Muis’ makes two basic points about the relationship between students’ epistemic beliefs and task definition. One is that students’ task definitions play a significant role in SRL and epistemic beliefs are one component of those definitions. The other is that, if students’ epistemic beliefs about the subject to be learned (mathematics in Muis’ model) are congruent with the epistemic nature of the subject per se, students’ epistemic beliefs should facilitate self-regulated learning; otherwise, their epistemic beliefs may constrain SRL.

One may ask what the mechanism is through which individual epistemological beliefs influence learners’ strategy use. Proposition b in Muis’ model (2007) attempts to provide an answer to that inquiry. In Winne and Hadwin’s SRL model (Winne & Hadwin,

1998), after task definition, self-regulated learners set specific goals to pursue by choosing strategies and tactics they predict are appropriate for achieving those goals. Goals inherently supply standards against which learners can metacognitively judge if a goal has been realized. Epistemic beliefs, according to Muis, facilitate or constrain facets of SRL through standards which are part of the multifaceted profile defining a goal. This is the second role epistemic beliefs play in a SRL process.

Primarily based on Hofer (2004), Kuhn (1999) and Winne (1995), Muis (2007) examined relations between epistemic beliefs and learners' self-reported and actual metacognitive strategy use in mathematical problem solving. She concluded from her empirical studies that epistemic beliefs serve as inputs to metacognitive processes in the form of standards. In turn, those epistemological standards influence the extent to which students engage in metacognitive processing. For example, she found that when students believed knowledge is certain and originates with authority, they set the standard that one authoritative source of information is sufficient to judge if a statement is correct. Accordingly, once students found one source from the authority (e.g., either teacher or textbook), they would quickly accept it even if that information was incongruent with prior knowledge.

In the context of the current study, Muis's conclusion (2007) leads to a hypothesis about how epistemological beliefs could affect relations between judgments of learning (JOLs), selection of items and allocations of time for study. For example, it could be anticipated that students who believe in quick learning would tend to study items they judge easy to learn rather than those they judge difficult to learn because studying easy items and spending less effort fits their belief in quick learning.

Last, proposition d in Muis' model supports the idea that the relationship between epistemic beliefs and SRL is reciprocal. That is, epistemic beliefs feed important information into the SRL processes while SRL processes in turn feed information back into epistemic beliefs. The first part of this statement was revealed in the analyses done in the last section. The second part suggests that learners' epistemic beliefs vary as the function of products generated in any phase of a self-regulated learning process. For example, belief about the certainty of knowledge may eventually change when learners recognize that multiple answers to a given problem are possible through their self-evaluation.

In summary, these models lead to hypotheses that students' personal epistemology influences how they regulate selection of study targets and allocation of study time.

Challenges in Measuring SRL

To examine empirically the role of multiple motivational variables and epistemological beliefs in moderating relations between metacognitive monitoring and control, a remaining problem is how to measure those variables. This involves a classic and fundamental issue in SRL research since the term self-regulated learning was coined three decades ago. Winne (2005) pointed out that, "Modeling SR has so far been more an analytic activity than an empirical one" (p. 236). Why? His diagnosis was that partly "we have lacked tools for gathering data that are critical to mapping events that constitute SR." (p. 236).

This classic issue has not yet been fully resolved. Thus far research on SRL has evolved along two lines forward: developments in theoretical paradigms and

methodologies (Zimmerman, 2008). Prosperity in SRL theories and models does not mean that we should devalue the ongoing commitment to develop more effective methodologies that empower researchers to unobtrusively capture the on-the-fly events that constitute SRL processes (Winne & Jamieson-Noel, 2002; Winne, Jamieson-Noel, & Muis, 2002; Perry & Winne, 2006; Hadwin et al., 2007; Zimmerman, 2008).

Process data about how learners use cognitive and metacognitive strategies and what they do to engage with the information while studying have primarily taken the form of self-report surveys. Researchers have increasingly realized the limitations of self-reports as measures of online (or dynamic) SRL (Perry & Winne, 2006) because self-reporting what and how learning unfolds is based on fallible memory. Therefore, in this section, I review studies on limitations of traditional methodologies for measuring SRL and emerging online process/event measures of SRL (Zimmerman, 2008; Perry & Winne). These methods allow studying SRL as aptitude or as event (process), respectively. Furthermore, this dual-character of SRL can be integrated into a coherent interpretative framework by examining the correspondence between self report/aptitude measures and traces of SRL in action.

Limitations of Traditional Methods and Emerging Trace Measures of SRL as a Process

Winne and Jamieson-Noel's seminal work (2002) turned a new page in SRL research by empirically examining the limitations of self-report surveys, the most common method of measuring SRL. The movement originated by their study is manifested in several recent articles by Winne and his colleagues (Perry & Winne, 2006; Hadwin et al., 2007).

According to Perry and Winne (2006), when researchers seek indicators about how learners use strategies and tactics while studying, self-report data may not be as reliable as expected, although such data can reveal learners' perceptions about their learning experience. Perry and Winne propose two accounts for the limitations of self-report methodology in measuring SRL as a process. First, learners' self-perceptions and evaluations of features of their cognitive processes are shaped in the context in which learning occurs. To the extent the context proposed in a self-report instrument's protocol mismatches that in which learning actually happens, self-reported perceptions of learning can misrepresent learning. Second, self-report measures cannot unobtrusively capture the components of SRL on-the-fly (Winne, 2004).

The solution to these issues that Winne and his research team propose is an e-learning environment that enables researchers to trace learners' processes while studying. Log files generated in this way unobtrusively record accurate, time-stamped events of how learners choose and manipulate content in the course of learning and SRL (Perry & Winne, 2006; Hadwin et al., 2007). This first version of this software tool, called gStudy, was used in this dissertation research. Details of the tool and how it was used will be presented in the chapter on methodology.

Alongside trace methods, Zimmerman (2008) comprehensively discussed recent efforts to assess students' online SRL, including think-aloud protocols, structured diaries, direct observations, and micro-analytic measures. He concluded that measures of SRL as aptitude (mainly by self-report surveys) have and will continue to provide useful information about students' self-perceptions and evaluations of learning. Online event measures of SRL, such as traces recorded by tools such as gStudy, offer detailed

information concerning the interplay among the various self-regulatory processes in real time. His summary matches Hadwin et al.'s (2007) that research needs to (a) augment self-reports of SRL with fine-grained traces of actual student actions as they study, and (b) examine relationships between actual actions and learners' self-perceptions of learning activities. Specifically, in this study, I will assess how learners' allocate study time (regulation of cognition) to a given item and examine how this is guided by their perceived difficulty of that item (metacognitive judgment) as well as other individual difference variables.

Eye Tracking Data Can Augment Computer Logfile Data in Measuring Self-Regulatory Processes

Simply speaking, eye tracking research dates back to the beginning of the 20th century when researchers discovered many basic facts about eye movement, including saccadic suppression, saccade latency, and the size of the perceptual span (Duchowski, 2002). Nowadays, eye tracking technologies are primarily used in three areas: neuroscience, psychology, and computer science. Duchowski observed two themes in neuroscience involving the application of eye tracking methods. One is the mechanism of neuronal activity related to eye movements. The other is to identify functional brain structures implicated in attentional behavior wherein neuroscientists combine eye movement recording data with functional brain imaging that tracks a subject's cortical activation during attentional tasks. In the field of psychology, researchers are particularly motivated to apply eye tracking technologies to reading and other visual information processing contexts such as scene perception, visual search, and so on.

Three basic vital empirical findings were summarized by Duchowski (2002). First, when reading English, on average, readers' eye fixations last approximately 200–250 ms

and the mean saccade size is 7–9 letter spaces. Second, eye movements are influenced by textual and typographical variables which include the difficulty of the text, the quality of print, line length, and letter spacing. Third, mean gaze fixations are longer when reading aloud or listening to a voice reading the same text than in silent reading.

The intent to use eye tracking technology in this research originates from the need to compute the exact time each participant attends to specific information when they study and reread. Visual attention was operationalized in terms of gaze time allocated to a pre-designated region of text that presents a specific proposition about the information studied validated as associated with readers' visual attention (Parkhurst et al., 2002; Isaacowitz, 2006). Unlike think-aloud protocols, eye tracking technologies offer the advantage of unobtrusively obtaining data about how learners allocate attention in real time without distracting them from a primary task (Duchowski, 2002). These data fill an "empty space" in software log files that trace learners' engagements with information by detailing how attention is allocated when learners are not using one of the software's tools for studying, such as opening a window, labeling content, or making notes.

Summary

This chapter started off with an overview of current theories and research of self-regulated learning. Emphasis was placed on the theoretical key of SRL theories – human agency, a fundamental concept in Bandura's social cognitive theory (2001), and its relation to two essential elements of SRL – metacognition and motivation. Second, the nature and constituents of metacognition as well as the lines of metacognition research were presented. Based on that, several main issues in metacognition were introduced such as the bases of metacognitive judgments, the control function of metacognition, and so on.

On this foundation, I presented the research questions that this dissertation research investigates. Specifically, I will explore if the relation between students' metacognitive judgment and their patterns of regulation of cognitive process correlate with motivational variables and epistemological beliefs.

In this study, the dependent variable is the relation between individual learners' judgments of learning (JOLs) and their study time allocation (control of cognitive resources). Independent variables include motivational variables, personal epistemology variables, and other personal psychological variables that have some likelihood of influencing SRL processes.

This research confronts a significant challenge concerning the measurement of constructs needed to test this model. For example, how can SRL be measured as a process on-the-fly? To address this need, I drew on features of a state-of-the-art computer-based learning environment augmented by eye tracking data to fill in spaces in the time stream of data where the software tools that trace cognition are not in use.

Chapter 3

Method

This chapter presents the method used in the study. First, characteristics of the people who participated in the experiments are described. Second, instruments used to measure the independent variables and the dependent variable are presented. Emphasis is placed on using advanced technologies to assess two aspects of the dependent variable: online judgments of learning and study time allocation. Third, the protocol is detailed. The most important part of this section describes the temporal sequence of measures of the dependent variable. Fourth, operational definitions of the dependent variable and strategies for processing and analyzing the empirical data are given alongside the rationale for using logistic regression to address the research question.

Participants

One hundred students at Simon Fraser University (SFU) volunteered to participate in the experiment. Due to some technical problems that will be explained in detail in the section regarding the technologies used in the study, there are only 75 valid recordings that were used for data analysis. All participants signed a consent form (Appendix 2) that was approved by Office of Research Ethics at SFU.

The participants had a wide variety of subject knowledge backgrounds. Students majoring mathematics were deliberately excluded because the content studied in the experiment was a mathematical topic – the fundamental division theorem.

Table 1.

Summary of Demographic Information

Female	Male	English	Other languages	Undergraduate students	Graduate students
49	26	30	45	45	30

Forty five participants were undergraduate students (60%) and 30 were graduate students (40%). There were 49 female (65.33%) and 26 male students (34.67%). Forty five participants reported English was not their first language. Data on the participants' language background should not be considered a robust index of English proficiency; the measure on language background essentially tended to be an index of ethnic background.

Instruments

There are two kinds of instrument used in the experiment. One is instruments used to measure independent variables. Some of these measures were administered at the beginning of the experiment, prior to participants engaging in the learning activity. Others were administered at the end of the experiment.

The second kind of instrument measured the dependent variable which can be viewed as online, real-time measures on learner's metacognitive processes. This is the most challenging part in relation to measurement in the study, so it will be introduced in a separate section focusing on the tools used to measure individuals' judgments of learning and study time allocation.

Self-Report Surveys Used To Measure Individual Difference Variables

Four groups of independent variables were measured in the study representing 25 theoretically distinct facets shown in Table 2. In the first group, six components of motivational beliefs were measured by the Motivated Strategies for Learning

Questionnaire (MSLQ) (Duncan & McKeachie, 2005). According to Duncan and McKeachie, a social-cognitive view of motivation and learning strategies was the basis of the MSLQ. Students were modeled as active processors of information whose beliefs and cognitions mediated important instructional input and task characteristics. They pointed out that The MSLQ has not only been used in numerous research studies on self-regulated learning but also in courses for self-evaluative purposes. The MSLQ has proven to be a reliable and useful tool for examining students' motivation and reports of using learning strategies.

The full MSLQ has 81-items. This study only used 6 motivation scales containing 31 items that assess intrinsic goal orientation, extrinsic goal orientation, task value, control of learning beliefs, self-efficacy, and test anxiety. Each item is scored on a 7-point Likert scale, from 1 (not at all true of me) to 7 (very true of me). The score on each scale was the mean of items that make up that scale. For example, self-efficacy has nine items. An individual's score on self-efficacy was the average of the nine responses to items after reversing any items presented in the negative.

The 28-item Epistemic Belief Inventory (EBI) (Schraw, Bendixen & Dunkle, 2002) was used to measure five categories of epistemological beliefs identified by Schommer (1990): omniscient authority, certain knowledge, quick learning, simple knowledge, and innate knowledge. Like the MSLQ, each item is scored on a 7-point Likert- scale ranging from 1 (strongly disagree) to 7 (very strongly agree). Because the number of items differs for each scale, scores were mean item scores. For example, the dimension of certain knowledge has six items. The score on this belief is the mean of these six items.

The Metacognitive Awareness Inventory (MAI) (Schraw & Dennison, 1994) was used to assess participants' knowledge of cognition and regulation of cognition involving 52-items in total. Knowledge of cognition (17 items) is composed of three dimensions: declarative knowledge, procedural knowledge, and conditional knowledge; regulation of cognition (35 items) is composed of monitoring, planning, information management strategies, debugging strategies, and evaluation. Rather than using Likert-scale, each item in MAI is scored on a 100-point scale.

Table 2.

Individual Difference Variables

Motivation (6 scales)	Personal epistemology (5 scales)	Metacognitive awareness (8 scales)	Other psychological processes (6 scales)
intrinsic goal orientation, extrinsic goal orientation, task value, control of learning beliefs, self-efficacy, test anxiety	omniscient authority, certain knowledge, quick learning, simple knowledge, innate knowledge	declarative knowledge, procedural knowledge, conditional knowledge, monitoring, planning, information management strategies, debugging strategies, evaluation	self-perceived capability of mental calculation, and of mental thinking; math anxiety, task interest, feeling of being challenged, the recall of items selection for restudy, calibration

In addition to the three standard self-report instruments, a fourth set of measures included a pre-questionnaire (Campbell, 2007), the Math Anxiety Rating Scale (MARS) (Hopko, 2003) and a post-questionnaire (See Appendix 9, 8, & 11). The pre-questionnaire uses a 5-point scale to assess learners' self-evaluation of their general capability to carry out mental calculation of one and two-digit numbers, and

mental/logical thinking. The post-questionnaire measured participants' attitudes toward the experiment they just finished using items about: personal interest, feeling of being challenged, and the recall of items selected for restudy. The last item concerns a participant's self-report of regulation of study time allocation as a reflection of metacognitive control.

Achievement Test

A test of understanding the material on the division theorem was developed. It consisted of 5 true-false and 5 multiple-choice questions. The test is reproduced in Appendix 10. After answering each question, participants rated their confidence in correctly answering the question to generate a measure of response confidence. Ratings were made on a 10-point scale on the question "Please rate how confidently you believe your last answer was correct. 0 indicates 0% confidence --- 10 indicates 100% confidence." The independent variable, calibration, is computed as the absolute value of the difference between a participant's mean score on the achievement test and the mean value of that person's confidence judgment.

It should be noted that a pre-test of the Division Theorem may seem a useful measure for post-analyses. However, because answering a pretest almost certainly generates judgments of knowledge that could contaminate subsequent JOLs, a pretest was not administered.

Tools Used to Measure the Dependent Variable

As noted in Chapter 2, SRL researchers face a large challenge – how to accurately measure online SRL processes or events as they happen in real time. This problem was addressed by using gStudy software and an eye tracking system to measure the two

components of the dependent variable – judgments of learning (JOLs) and study time allocation.

gStudy

gStudy is multi-featured multimedia software developed by the research team led by Professor Philip Winne at Simon Fraser University (Winne, Hadwin, Nesbit, Kumar, & Beaudoin, 2005; Perry & Winne 2006). gStudy has many features that facilitate research on learning and self-regulated learning. For students, gStudy is a learning tool in which multimedia subjects are presented in structured packages called learning kits. Learners create “information objects” (IOs) such as notes with templates (schemas), glossary entries with templates, indexes of IOs, concept maps, and records of chats with peers or mentors/teachers. gStudy is a shell such that the topic of a learning kit can be anything presented as text, diagrams, photos, charts, tables, and audio and video clips using the display language of the world wide web, HTML. gStudy unobtrusively records trace data that are accurate, time-stamped descriptions of observable interactions between learners and information they engage with while learning (Perry & Winne, 2006). For example, whenever a learner creates a note in gStudy, gStudy traces in very fine-grained detail all the events the learner performs, e, g., which text was selected as the material to be annotate, when it was selected, which note template the learner chose to use for annotating, which slots in the note template the learner filled in, what information was included in the note, and more (Winne, 2006). All these data trace the learner’s engagements with content in the learning kit.

The Eye Tracking System

The second part of the dependent variable, metacognitive control, was measured as time allocated to each of 36 pre-designated areas in the learning text using the Tobii 1750 Eye Tracker and eye-tracking analysis software. (More information can be found at http://www.srlabs.it/pdf/Tobii1750_PD_2.pdf.)

The Tobii eye tracker generates infrared beams that reflect off the corneas of the user's eyes. Built-in image sensors collect the reflection patterns together with other visual information about the user. Sophisticated image processing algorithms are used to calculate the three-dimensional position in space of each eyeball, and finally the gaze point on the screen; that is, where the user is gazing. According to its documentation, Tobii eye trackers can track eye gaze of virtually everyone regardless of ethnic origin, age, or whether users wear glasses or contact lenses. ClearView 2.0, the eye tracking software affiliated to Tobii 1750 Eye Tracker can compute the gaze time for any areas of interest at which users gaze.

Materials

This research advances prior studies of metacognition that used either paired associates or expository texts as stimuli (Wiley, Griffin, & Thiede, 2005). Rather than measuring metacomprehension over an entire paragraph as has been done in prior metacomprehension research (Wiley et al. 2005), in this study, targets for JOLs are separate but conceptually interrelated propositions embedded in the text. Target contents are pre-designated and shaded as shown in Figure 1.

The text participants studied was about the Division Theorem (See Appendix 12) and was designed by Dr. Campbell (a member in the supervisory committee) whose

expertise is in the field of mathematics education and educational neuroscience.

Difficulty was intended to be at the high school level. The text was displayed on the main window of gStudy.

Figure 2 illustrates what the learning material looks like when displayed in gStudy. Within the six-page text were 36 pre-designated targets about which participants made judgments of learning. The targets were identified to represent conceptually important mathematical knowledge, according to Dr. Campbell. The features of gStudy that are relevant to this study will be introduced briefly in a subsequent section.

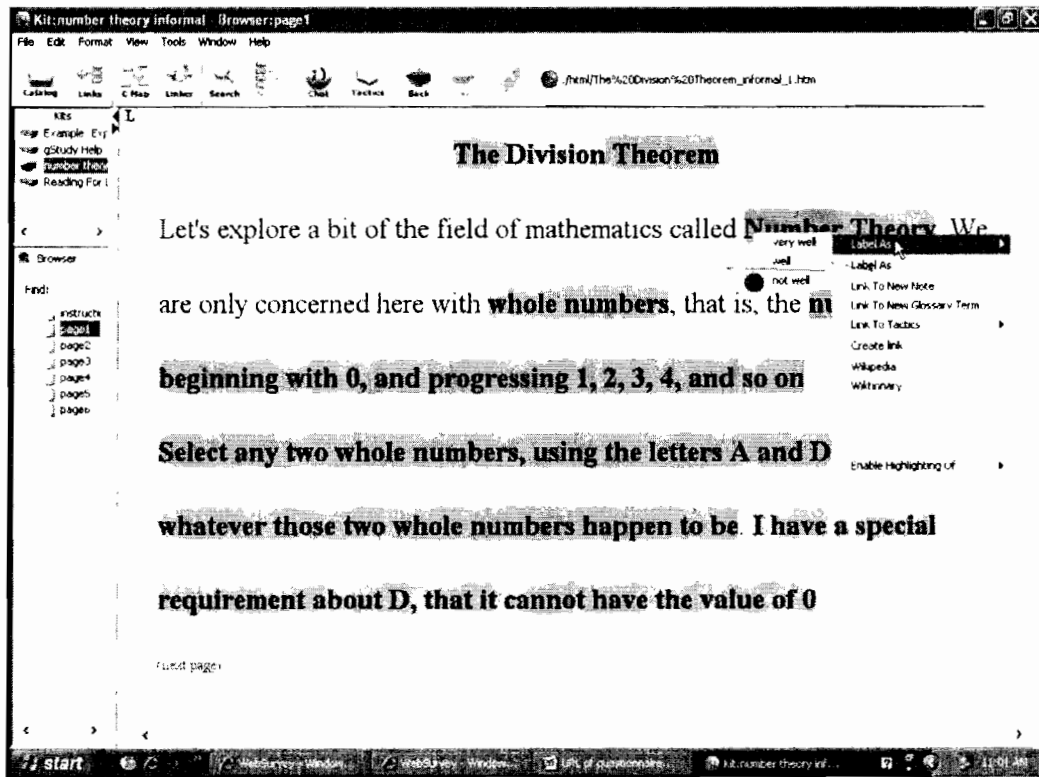


Figure 2. Layout of the learning material displayed on the main window of gStudy tool

Procedure

Participants were first welcomed to the lab and provided information about the experiment so they could decide whether to offer informed consent to participate. Next,

each participant entered the observation room and participated in an eye tracking calibration task using the built-in function of the Tobii 1750 Eye Tracker. During the whole period of the experiment, each participant sat in the front of the Tobii 1750 Eye Tracker to complete all activities.

The experiment had three parts lasting approximately 60 minutes in total. First, participants completed the online questionnaires to record demographic information and respond to self-report inventories assessing motivation (goal orientation and self-efficacy), epistemological beliefs, and metacognitive awareness, and components of the pre-questionnaire survey.

Second, participants used gStudy to study the text on the division theorem in two 10-min phases: initial study and restudy. The detail of instructions provided participants is presented in Appendix 13.

During the first 10 min study period, pages were presented in order and participants were not allowed to review prior pages once they had clicked a button to progress to the next page in order to reduce any possibility whereby restudy may occur during the phase of initial study to enhance the validity of the dependent variable measurement. Participants used gStudy's labeling tool to label each target to indicate their judgments of learning (JOLs) that target information by answering the question: "Please label each shaded region with your judgment of how well you think you have learned the content of each shaded region: very well, well, or not well". gStudy recorded the time and label chosen corresponding to judgments of learning. Ideally, each participant should have produced 36 JOLs after they completed the 10-minute study session.

Following a 1 min rest period, participants were offered up to 10 min to restudy the material. They could stop studying at any time within that 10-minute period when they judged they are ready to take the test. Thus, participants self regulated what they restudied and the pace of restudy.

Next, participants took the achievement test. After answering each question in the test, they rated the confidence (probability) of the correctness of each last answer. That is so-called confidence judgment or response confidence. Finally, they completed the short post-questionnaire.

Data Analyses

This sub-section describes three key features related to processing and analyzing the empirical data obtained in the experiments. One concerns how the dependent variables are operationally defined. The second is about the main statistical technique – logistic regression, used in this study to quantitatively address the research question. The third is how the raw eye tracking data were pre-processed before they were imported to SPSS for analysis.

Operational Definitions of the Relationship between Online JOLs and Restudy Time Allocation

Measuring the dependent variable involves the examination of the correspondence between the JOL each participant assigned to an item during their initial study and the gaze time they allocated to the corresponding targeted information while restudying. Due to the complexity of defining and computing gaze time, this section operationally defines the dependent variable – the relationship between JOLs and restudy time allocation, and introduces the statistical technique, logistic regression analysis, which was used to

examine the association between the dependent variable and each of the independent variables.

Three-Level Categorical Dependent Variable

In the first phase of study, each participant was required to assign one of three categories describing a judgment of learning (JOL) to each pre-designated target in the learning text. The total restudy time allocated to a pre-designated target was computed by summing the gaze times on that region during the whole restudy period. Prior to computation, each target was enclosed by rectangle boxes, termed an area of interest in the eye tracking software (see Figure 3). The operational definition of the dependent variable is the average gaze time for targets to which a participant assigned a judgment of learning: very well learned, well learned, not well learned. Specifically, the average gaze time for a judgment of learning is the division of the total gaze time for all targets assigned that judgment of learning by the number of targets assigned that judgment of learning. For instance, if a subject labeled 10 targets not well learned and he/she spent 10000 ms in total inspecting those 10 targets, the average gaze time for not well learned targets for that participant is 1000 ms. Thus, if a participant assigned each level of judgment of learning to some contents, s/he was characterized by average gaze times for each of the three possible levels of judgments of learning. Each participant was characterized in terms of one of the three levels of judgment of learning based on the largest average gaze time for a level of judgment of learning.

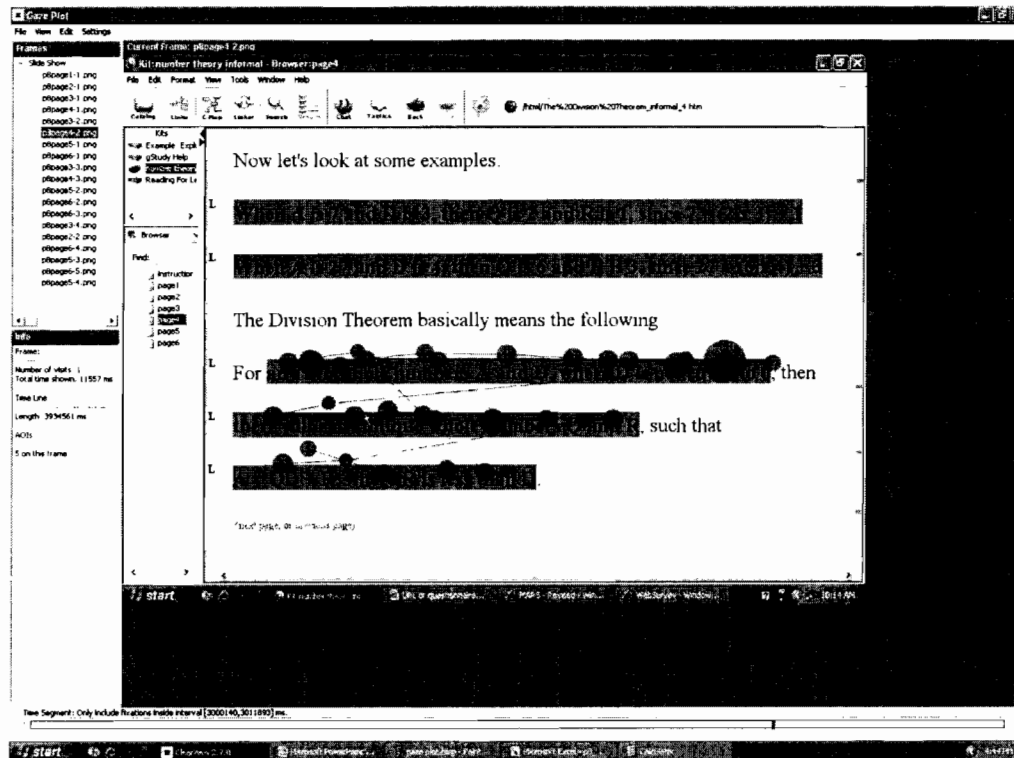


Figure 3. Targets for Computing Gaze Time and the Hot Spot of Eye Tracking Data

One may argue that for a participant, the total gaze time on a target obtained from the software does not necessarily equal the time that person mentally attended to and cognitively processed information in that region because that participant could mentally process information of a target region without gazing at it. The issue regarding the association between visual attention and innate mental processing was discussed in Chapter 2 (see pp. 59-63).

Participants were classified into one of three categories based on the largest average restudy times to for information judged not well learned, well learned, and well learned. This leads to a three-level categorical dependent variable. For example, during the period of restudy, subject #28 on average spent 6008.25 ms reading each target judged not well learned, 2926.55 ms reading each target judged well learned, and 3196.43 ms reading each very well learned region. As a result, #28 was grouped into the

category of inclining to allocate most of the restudy time to information judged not well learned. Classifications were coded 1 = not well learned, 2 = well learned and 3 = very well learned.

Two-Level Categorical Dependent Variable

Among the 75 participants, 60 who chose all three categories of JOLs while the remaining 15 generated only two categories of JOL regions. All participants also can be classified into two categories: inclined to restudy information judged well learned and inclined to restudy information judged not well learned. That generates a two-level categorical dependent variable. Specifically, those who allocated most restudy time to the not well learned targets are grouped into the category of not well learned; and, those who allocated most restudy time to either well learned or very well learned contents are grouped into the category of well learned. For instance, the average gaze time that Subject #27 allocated to the well learned region was 2690.03 ms and the average gaze time to the very well learned region was 1096.00 ms. Subject #27 did not have the category of not well learned. Subject #27 can be grouped into the category of not well learned.

A subsequent question is which sample should be used to address the research questions, the one of size 75 or 60. In terms of statistical power to detect group differences, the two-level dependent variable appears better because it permits using a larger sample. This issue will be elaborated in the chapter on results.

Logistic Regression Analysis

Regardless of two-level or three-level, the dependent variable in the study is categorical or discrete. As mentioned earlier, the independent variables are continuous.

This combination of dependent variable and independent variables fits the use of logistic regression analysis to examine which psychological processes among those independent variables can predict the individual student's group membership (e.g., allocating more restudy to not well learned contents versus to well learned targets) (Tabachnick & Fidell, 2001). Specifically, logistic regression analysis computes the probability of a particular outcome for each case. For example, it assesses the probability that a given participant in this study was inclined to allocate more restudy time to targets judged not well learned or targets judged well learned given his or her self-reported motivation, personal epistemology, and other psychological properties. According to Tabachnick and Fidell, a considerable advantage of logistic regression is that the independent variables (predictors) do not have to be normally distributed, linearly related, or of equal variance within each group. In addition, since the nature of the research questions is concerned with what kind of individual difference variables can predict the category of individual learner's restudy time allocation based on their JOLs, logistic regression analysis appears to appropriate.

Issues of Measurement Validity of Gaze Allocation Data

The dependent variable involves measuring individuals' allocations (metacognitive control) of gaze time on targets in the text. Because such allocations are expected to reflect judgments of difficulty of the text, it is appropriate to eliminate as many confounding factors as possible. What factors other than the difficulty of the information affect readers' reading time? Research (Bisanz, Das, Varnhagen & Henderson, 1992; Keenan & Brown, 1984; Duchowski, 2002) shows that for readers of any age, reading time/rate is associated with several microstructural components of reading: *number of words, frequency of content words, frequency of propositions*, and

syntax. Thus, the question here is whether to eliminate effects due to these factors so that gaze time reflects more purely learners' attention to particular targets of information. If the answer is yes, the next question is how to do this.

Consider relations among gaze time, length (number of words) and difficulty where difficulty is computed as the ratio of al JOLs assigned as "not well learned." For instance, the frequency of not well learned, well learned, and very well learned labeled to the first region on page 3 by all the subjects was, respectively, 16, 23, and 43. Accordingly, the difficulty of that target region is $16/(16+23+43) = .195$. A correlation analysis shows that the length of target is strongly correlated with the total gaze time allocated to each target ($r = .798, p \leq .001$). No correlation ($r = .028, p > .80$) was detected between the relative difficulty of target and the total gaze time.

This result might suggest the necessity to rescale gaze time to eliminate the effect of length of the target. However, consider whether the relationship between length and the gaze time varies as a function of the level of JOL. It does not as shown in Table 3. In other words, the length of target region and the gaze time on each region is strongly correlated regardless of the level of JOL (not well learned, well learned, or very well learned).

What does this finding mean regarding the issue of whether to normalize gaze? If the study was primarily concerned with the absolute value of the gaze time on each target, the data should be normalized. However, this study is only concerned with the relational characteristics of gaze time rather the absolute value of it; that is, among the three kinds of JOL regions, which was allocated the most restudy time. Thus, normalizing is not required.

Table 3 also displays the correlation between the number of proposition in each region and the total gaze time. A proposition refers to the smallest unit of meaning in the form of separate assertion (Bruning, Schraw, & Norby, 2004). For example, shown in Figure 2 above, the first sentence on page 4 is “When A is 7 and D is 3, then Q is 2 and R is 1, since $7 = (2 \times 3) + 1$.” This contains 5 proposition: “A is 7”, “D is 3”, “Q is 2”, “R is 1”, and “ $7 = (2 \times 3) + 1$ ”. Thus, the overall conclusion is that defining the dependent variable in this study does not require taking into account the microstructural components of words, frequency of content words, proposition, and syntax.

Table 3.

The Pearson Correlation Between The Pre-Designated Region Length, The Number of Proposition And The Total Gaze Time of Each Type of Regions.

	gaze time of very well learned targets	gaze time of well learned targets	gaze time of not well learned targets
Length of target	.65**	.51**	.58**
Number of propositions	.83**	.44**	.45**

** $p < .01$

Chapter 4

Results

The research questions are whether students' motivation, epistemological beliefs and individual difference variables such as metacognitive awareness influence the relation between metacognitive judgment and metacognitive control in self-regulated learning (SRL). To answer these questions, results are presented in four sub-sections in this chapter. Section 1 presents results about the independent variables measured by self-report surveys. Section 2 will display results about the association between psychological variables measured by self-report surveys and patterns of actual allocation of restudy time reflected by eye tracking data. Section 3 will show the association between the patterns of actual restudy time allocation and self-reported restudy time allocation. Based on this association, section 4 will explore accounts for the variance between these two different patterns by relating them respectively to personal psychological processes. These analyses illuminate the distinctive psychological bases between the online, objective, actual metacognitive processes and self-reported, subjective, recalled metacognitive processes.

Three participants did not satisfy the eye tracking calibration test and were excluded. Two participants could not complete the all activities of the experiments were excluded for further analyses. The eye tracking data sets of the first six participants were deleted by accident due to lacking of the experiences related to using this system. The eye tracking data obtained from the remaining 14 subjects are incomplete. This is why there were only 75 valid data for further analyses in this dissertation research.

Results of the Self-Report Surveys

Table 4 displays the means, standard deviations, and Cronbach α reliability coefficients for each variable measured by widely used self-report survey inventories. Table 5 presents descriptive statistics from the Math Anxiety Rating Scale (MARS), the pre-and post-experiment questionnaires, and the two measures from the posttest. In general, after excluding outliers, all these variables were normally distributed according to the values of skewness and kurtosis shown in Table 4. All skewness values were close to zero (< 1).

This study sets .65 as the threshold for a sufficient reliability coefficient (Cronbach α). Eleven variables with $\alpha < .65$, bolded in Tables 4 and 5, are not considered further: two motivational variables, four epistemological beliefs variables, four metacognitive awareness variables, and one variable describing self-perception of math/reasoning capabilities.

For the motivational variables, α coefficients were high for self-efficacy (.95), task value (.87), and test anxiety (.74). The other three motivational variables have moderate internal consistency reliability. This pattern is in accordance with the internal consistency of motivational variables reported in Duncan and McKeachie's study (2005).

Table 4.

Mean, Standard Deviation, and α Reliability Coefficients for Motivational, Epistemological Beliefs, Metacognitive Awareness, and Math Anxiety Variables

Self-report Inventories	Mean	SD	α	Skewness	Kurtosis
<u>MSLQ</u> ¹					
Intrinsic goal orientation	5.03	.85	.64	-.61	.42
Extrinsic goal orientation	3.91	1.44	.65	.16	-.43
Task value	3.91	1.17	.87	-.22	.06
Control of learning beliefs	5.14	1.01	.63	-.24	-.43
Self-efficacy	4.80	1.20	.95	-.66	.72
Test anxiety	3.32	1.28	.74	.34	-.42
<u>EBI</u> ²					
Omniscient Authority	3.77	1.09	.63	.08	.02
Certain knowledge	3.83	.65	.00 ³	.02	-.34
Quick learning	3.23	.95	.43	.17	-.86
Simple knowledge	4.75	.96	.56	.40	.80
Innate knowledge	4.02	1.02	.68	.05	-.70
<u>MAI</u> ⁴					
Declarative knowledge	5.12	.76	.73	-.70	.53
Procedural knowledge	4.94	.86	.62	-.03	-.64
Conditional knowledge	4.95	.80	.49	-.88	.93
Planning	4.49	.94	.71	-.31	.71
Monitoring	4.73	.84	.74	.52	.27
Information management strategies	5.09	.76	.67	-.33	-.02
Debugging strategies	5.16	.85	.52	-.45	.68
Evaluation	4.56	.88	.63	-.11	.80
<u>MARS</u> ⁵					
	2.32	.69	.87	.46	.44

Note: Bold variables are excluded from further analyses due to low internal consistency reliability, $\alpha < .65$.

Note: SD=Standard Deviation, α = Cronbach's Alpha, ¹7-point scale

² 7-point scale

³ This coefficient is set to .00 because the computation yielded a theoretically impossible negative value.

⁴ 10-point scale

⁵ 5-point scale

Descriptive statistics for the three clusters of variables from the post-experiment questionnaire, pre-questionnaire on self-perception of math/reasoning capabilities, and posttest are displayed in Table 5. Results from the post-experiment questionnaire about the self-reported restudy time allocation (metacognitive control) will be reported in a later section about the relation between learners' self-reported and their actual metacognitive processes.

The first scale in the pre-questionnaire is learners' self-perceptions of their capability of mental calculation of 1-2 digit numbers. The mean of that scale shows that most participants had quite high confidence in their capability. The reliability coefficients suggest that the internal consistency of these two scales in the pre-questionnaire is moderately reliable with the median of .75 after removing the component of math/logical thinking. Basically, these variables were normally distributed according to the values of skewness and kurtosis. Most participants seemed to be interested in the task, $M = 4.37$ (out of 7). The perceived challenge of the task is moderate, $M = 3.99$ (out of 7). The maximum score on the achievement test is 10 and the observed mean is 6.51. The achievement test is composed of 10 multiple or yes/no questions. The reliability coefficient is .67. This indicates that on average the participants' performance was moderate. In comparison, the mean confidence judgment was 8.14 (out of 10) suggesting that the majority of participants more confident about their performance in the test than was warranted. The calibration mean of 2.17 refers to the absolute value of the gap between an average participant's mean test score and the mean of JOLs for targets.

Table 5.

Descriptive Statistics for Pre- and Post-Questionnaire and Posttest

Inventories	Mean	SD	α	Skewness	Kurtosis
<u>Pre-questionnaire⁶</u>					
Mental calculation	4.28	.73	.84	.50	.97
Reading and recall	3.59	.59	.65	-.01	.06
Mathematically/Logical thinking	3.61	.50	.51	-.02	-1.34
<u>Post-questionnaire⁷</u>					
Task interest	4.37	1.71		-.84	.34
Perceived Challenge of task	3.99	1.74		-.31	-.82
<u>Posttest</u>					
Score ⁸	6.51	1.49	.67	-.20	-.18
Confidence judgment	8.42	1.11		.52	.37
Calibration	2.17	1.48		.48	-.54

Note: Bold variables are excluded from further analyses due to low internal consistency reliability, $\alpha < .65$.

Factors Underlying Patterns of Restudy Time Allocation

This dependent variable combines online metacognitive judgments of learning and metacognitive control reflected by restudy time allocation. In a binary classification, 75 participants were classified into two categories: a group allocating more gaze time to targets judged not well learned versus a group allocating more gaze time to targets judged well learned. In a trinary classification, those who only have only two categories of JOLs were excluded, leaving 60 participants grouped into one of three categories: allocating more gaze time to not well learned or to well learned or to very well learned. For example, participant #64 only had two categories of JOLs: very well learned and well learned. So, that participant was excluded from the analyses in the trinary classification. In this

⁶ 2-item, 5-point scale

⁷ 7-point scale

⁸ 10 questions

classification, the 60 participants who have three categories of JOLs can still be grouped into two categories as in the binary classification.

A frequency analysis shows that among the 75 participants, 37 were found to allocate more restudy time to the targets not well learned, and 38 allocated more restudy time to the targets well learned. Among the 60 participants who used all three levels of JOLs, 27 participants allocated most restudy time to not well learned targets. 20 participants allocated most restudy time to well learned targets and 13 participants allocated most restudy time to very well learned targets. The distribution is shown in Table 6 below. This simple finding modifies Dunlosky and Hertzog’s model providing empirical evidence that learners do not always spend more study time on information they judge difficult to learn. In other words, the relation between metacognitive judgment and control in SRL is more complex than the discrepancy-reduction model describes.

Table 6.

The Distribution of Restudy Time Allocation to Different Types of Judgments of Learning in the Cases of Two Different Methods for Defining Categories

<u>Binary Classification of JOL</u> (N=75)	Well learned		Not well learned
Number of Participants	38		37
<u>Trinary Classification of JOL</u> (N=60)	Very Well Learned	Well Learned	Not Well Learned
Number of Participants	13	20	27

What factors underlie learners’ tendencies to allocate restudy time? Two multivariate logistic regression models were used to investigate relationships between the 17 personal factors and the patterns of restudy time allocation (metacognition) separately for the two classifications: binary and trinary. Results of these two multivariate logistic regression models are shown in Table 7 and Table 8, respectively. It should be noted that

three important steps that were taken before running the regression model to ensure the interpretive power of the model.

First, outliers were controlled. To detect the univariate outliers, the z-scores of the values of all predictors were computed. Cases with z-scores > 3.08 ($p < .001$) were declared univariate outliers. To preserve data, actual outlying values were replaced with trimmed scores equal to one raw scale unit greater than the highest score falling below the criterion z-value of 3.08 (Tabachnick & Fidell, 2001). By doing so, six univariate outliers were detected and adjusted. Then, Mahalanobis distances for each of the 17 predictors was computed, and critical chi square value was chosen at $\alpha = .001$ and $df = 17$, which is 40.79 (Tabachnick & Fidell). Relative to this cutoff value, no multivariate outliers were identifiable.

The second issue affecting statistical power of the multivariate logistic regression is the ratio of cases to variables. A commonly used rule for the minimum number of cases for a given number of variables is $50 + m$, where m is the number of predictors in the regression (Green, 1991). In this study, m is 17, so $50 + 17 = 67 < 75$, the number of cases in the logistic regression model. Thus, the ratio of cases to variables is acceptable for this multivariate logistic regression model.

The third issue that might affect the analysis is multicollinearity among the predictors. Statistics books (Meyer, Gamst, & Guarino, 2006; Tabachnick & Fidell, 2001) introduce several approaches to detecting multicollinearity such as bivariate correlations, multivariate tolerance, and variance inflation factor (VIF). These authors agree that only if a bivariate correlation is greater than 0.8 or 0.9 should researchers worry about

multicollinearity. Bivariate correlations among the 17 predictors are shown in Appendix 1. The maximum correlation is 0.703.

The next two criteria for determining multicollinearity are examined in terms of results from a multivariate regression model (not logistic regression model) involving the 17 predictors describing 75 cases for the binary categorical dependent variable.

According to Meyer et al. (2006), only if the multivariate tolerance of a predictor is 0.01 or less or when the variance inflation factor (VIF) of a predictor is greater than 10 is multicollinearity indicated. In the multivariate regression model, neither threshold was exceeded. Thus, all three indicators converge to indicate that multicollinearity is not a problem in this case.

The 17 predictor variables were used in two multivariate logistic regression models where the outcome variable was a categorical classification, the binary classification of restudy time allocation in one analysis and the trinary classification in the other analysis.

Results of the Binary classification

Results for the binary classification of restudy time allocation are shown in Table 7 below. The pattern of restudy time allocation is statistically detectable in this model at $p = .087$, $\chi^2 (17, n=75) = 25.36$. Predictors that statistically detect the difference in this pattern of restudy time allocation include two motivational variables: external goal orientation ($p=.022$) and task value ($p=.070$), two metacognitive awareness variables: monitoring ($p=.024$) and planning ($p=.074$), one self-perception of learning task variable: task interest ($p=.064$), two achievement-related variables: posttest score ($p=.078$) and calibration ($p=.025$). Using the traditional value for avoiding Type I error of $p \leq .05$,

three individual difference variables can statistically discriminate the two patterns of restudy time allocation.

Table 7.

Results of the Multivariate Logistic Regression on Pattern of Restudy Time Allocation - Binary Classification Sample (N=75)

Model	χ^2 25.36			df 17	p .087	
	<u>Parameter Estimates</u>					
Predictors	B	S.E.	Wald	df	p	Exp(B)
<u>Motivation</u>						
External goal orientation	-.853	.372	5.262	1	.022	.426
Task value	.832	.458	3.294	1	.070	2.297
Self-efficacy	.270	.513	.276	1	.599	1.309
Test anxiety	.139	.310	.201	1	.654	1.149
<u>Metacognitive awareness</u>						
Monitoring	1.580	.700	5.096	1	.024	4.856
Plan	-.963	.539	3.193	1	.074	.382
Information management strategies	-.358	.645	.308	1	.579	.699
Declarative knowledge	-.361	.647	.311	1	.577	.697
<u>Epistemological beliefs</u>						
Innate knowledge	.201	.320	.396	1	.529	1.223
<u>Self-perception of learning task</u>						
Task interest	.395	.213	3.435	1	.064	1.485
Task challenge	.048	.226	.045	1	.831	1.049
<u>Achievement-related constructs</u>						
Posttest score	.592	.335	3.115	1	.078	1.807
Confidence judgment	-.568	.416	1.865	1	.172	.566
Calibration	.863	.384	5.052	1	.025	2.370
<u>Perceived math-related capabilities</u>						
Math anxiety	-.165	.530	.097	1	.756	.848
Perceived calculation ability	-.222	.526	.178	1	.673	.801
Perceived memory capability	-.694	.780	.792	1	.374	.500

According to Tabachnick and Fidell (2001), interpreting the direction of the odds ratios, Exp(B), and the B coefficient as parameter estimates is determined by the way the outcome categories are coded. In this logistic regression analysis, not well learned is coded as +1, so it is called the “response” group and the other group is called a

“reference” group. The odds ratio, $\text{Exp}(B)$ or e^B is the ratio of the probability of being in the not well learned group to the probability of not being in reference group. For instance, for the monitoring variable, $\text{Exp}(B)$ is 4.856, so the probability of participants being in the not well learned group (response group) increases by a multiplicative factor of 4.856 with each one-unit increase in the predictor, monitoring.

The means and standard deviations of each group on each statistically detected predictor are displayed in Table 9. Specifically, those who were scored higher on the external goal orientation spent more reading time on the targets judged well learned. Those who attributed more value to the learning task allocated more time rereading to the not well learned targets.

An opposite tendency of restudy time allocation was found between the two metacognitive awareness variables – monitoring and planning. Those who scored higher on monitoring spent more restudy time on the not well learned targets than those who scored lower on monitoring. In contrast, the participants who got higher scores on planning spent less time reading the not well learned targets.

This finding stimulates metacognition researchers to further probe the roles of different metacognitive awareness variables in guiding actual metacognitive operations. The participants who retrospectively expressed more interest in the task tended to spend more restudy time on not well learned targets.

Interestingly, the test score functions differently in moderating the pattern of restudy time allocation. The higher the achievement posttest score, the more restudy time was allocated to the well learned targets.

Lastly, the most interesting finding in the binary classification is related to the role of the calibration variable as related to the association between JOLs and restudy time allocation. The poor calibrators tended to spend more restudy time on not well learned targets.

The above finding shows that the relation between JOLs and restudy time allocation can be accounted for by some personal factors. This conclusion can be further justified in the case of trinary classification of not well learned targets, well learned targets, and not well learned targets, as described next.

Results of the Trinary Classification

Results for the trinary classification of restudy time allocation are shown in Table 8. The pattern of restudy time allocation is statistically detectable in this model at $p = .063$, $\chi^2(34, n=75) = 47.44$. Predictors that statistically detect the difference in this pattern of restudy time allocation include two metacognitive awareness variables: monitoring ($p < .001$), and planning ($p = .095$), two achievement-related variables: test score ($p = .015$) and calibration ($p = .001$), and one perceived math-related capabilities variable: memory capability ($p = .002$).

No motivational variables were statistically detectable predictors of restudy time allocation in the trinary classification. In contrast, the perceived memory capabilities variable statistically detected the patterns of restudy time allocation in this case, which was not found in the binary classification. In both systems of classifications, binary and trinary, the metacognitive awareness variables and the achievement-related variables were statistically detected as predictors.

Table 8.

Results of the Multivariate Logistic Regression on Actual Pattern of Restudy Time Allocation - Trinary Classification Sample (N=60)

Model	Chi-Square	df	p
	47.439	34	.063
	<u>Parameter Estimates</u>		
Predictors	Chi-Square	df	Sig.
<u>Motivation</u>			
External goal orientation	1.671	2	.434
Task value	.669	2	.716
Self-efficacy	3.868	2	.145
Test anxiety	1.576	2	.455
<u>Metacognitive awareness</u>			
Monitoring	15.656	2	.000
Plan	4.705	2	.095
Information management strategies	4.364	2	.113
Declarative knowledge	1.090	2	.580
<u>Epistemological beliefs</u>			
Innate knowledge	1.234	2	.540
<u>Self-perception of the learning task</u>			
Task interest	3.244	2	.197
Task challenge	.646	2	.724
<u>Achievement-related constructs</u>			
Posttest score	8.464	2	.015
Confidence judgment	2.758	2	.252
Calibration	14.209	2	.001
<u>Perceived math-related capabilities</u>			
Math anxiety	2.559	2	.278
1-2 digit calculation ability	2.584	2	.275
Memory capability	12.506	2	.002

It should be noted that when the size of sample is 60, the ratio of case-to-variable does not strictly satisfy the standard criterion $50 + m$ ($m =$ the number of variables) $\geq n$ since $50 + 17$ (predictors) $= 67$ and $n = 60$.

Table 9 further elaborates the finding regarding the positive correlation between calibration scores and JOLs, and the negative correlation between test scores and JOLs. Interestingly, those who were confident in their reading and memory capabilities seemed

to allocate more restudy time to the intermediate JOLs (well learned) targets. However, this phenomenon did not repeat in the binary classification, so it will not be further discussed.

Table 9.

Mean and Standard Deviation of Each Reliable Predictor in Each Case

	<u>Binary Classification Sample (N=75)</u>		
	Well learned (n=38)	Not well learned (n=37)	
External goal orientation	4.04 (1.51)	3.77 (1.36)	
Task value	4.26 (1.26)	4.36 (1.08)	
Planning	4.68 (.90)	4.34 (.88)	
Monitoring	4.68 (1.00)	4.74 (.67)	
Task interest	4.00 (2.07)	4.78 (.95)	
Score	6.66 (1.28)	6.35 (1.69)	
Calibration	1.84 (1.30)	2.50 (1.59)	
	<u>Trinary Classification (N=60)</u>		
	Very well learned (n=13)	Well learned (n=20)	Not well learned (n=27)
Monitoring	4.46 (1.17)	4.70 (.93)	4.74 (.65)
Planning	5.21 (.76)	5.18 (.71)	5.08 (.61)
Score	6.85 (.99)	6.75 (1.45)	6.41 (1.62)
Calibration	1.26 (1.12)	1.85 (1.78)	2.55 (1.49)
Confidence in recall/reading	3.58 (.67)	3.83 (.49)	3.52 (.49)

Taken together, the results shown in Tables 7 and 8 indicate three robust personal factors underlying the relation between people’s judgments of learning and restudy time allocation: monitoring, test scores (cognitive achievement), and calibration (accuracy of confidence judgment of cognitive achievement). These variables represent two categories of learner characteristics: metacognitive awareness, and achievement-related constructs. This finding will be discussed in the next chapter.

Self-Reported Restudy Time Allocation

At the end of the experiment, each participant was asked to recall how they allocated restudy time in the experiment. Table 10 displays the distribution of these self

reports. Sixty percent of participants reported allocating restudy to material they recalled being difficult to understand. Other participants made different attributions for their restudy. Next, I explore (1) whether and to what degree the patterns of the participants' self-reported restudy time allocation are consistent with their actual restudy time allocations; (2) whether the self-reported pattern of restudy time allocation can be accounted for by motivation, metacognitive awareness, and epistemological beliefs; and (3) how the association of the self-reported restudy time allocation can help to interpret the findings presented earlier.

Table 10.

Distribution of Self-Reported Pattern of Item selection for Restudy (N=75)

Reason for selecting targets to restudy	Frequency
Difficult to understand	45
Easy to understand	7
Interesting to me	3
Possible test questions	12
No particular reason	8

Few participants nominated reasons for allocating study time other than because they judged information difficult. Thus, to achieve useful sample size, I classified the 75 participants into two categories: *selecting targets judged not well learned for restudy* (N=45) and *other reasons for restudy* (N=30).

Did participants who reported they tended to select targets not well learned for restudy really behave as they recalled? A CrossTab analysis displayed in Table 11 shows that 19 of the 45 participants (42%) who recalled they selected difficult targets for restudy actually allocated most restudy time to other kinds of targets. Meanwhile, 36% (11 out of 30) of those who recalled they selected others kinds of targets rather than the

not well learned ones for restudy actually allocated most time to the not well learned targets for restudy. This finding is surprising when it is noted that the interval between the restudy phase in the experiment and when participants recalled how they restudied was only about 10-20 minutes.

Table 11.

Comparison between Actual Restudy Time Allocation and Self-reported Restudy Time Allocation

	Actual patterns of item selection		
	Selecting the difficult targets	Selecting other targets	Total
Self-reported selecting difficult targets	26	19	45
Self-reported selecting other kinds of targets	11	19	30
Total	37	38	75

Factors Underlying the Pattern of Self-Reported Restudy Time Allocation

Prior research has not investigated (a) whether individual difference variables predict learners' recall of cognitive operations, and (b) if factors underlying self-reports about allocated reading time for restudy differ from those underlying actual restudy time allocation. To answer these questions, a multivariate logistic regression was conducted on the 17 predictors where the outcome variable was the self-reported restudy time allocation. The sample size of 75 is adequate for this analysis, as considered previously.

Table 12.

Results of the Multivariate Logistic Regression on Self-Reported Patterns of Restudy Time Allocation – Binary Classification Sample (N=75)

Model						
χ^2	df		p			
31.831	17		.016			
<u>Parameter Estimates</u>						
Predictors	B	S.E.	Wald	df	p	Exp(B)
<u>Motivation</u>						
External goal orientation	-.275	.380	.526	1	.468	.759
Task value	.351	.473	.551	1	.458	1.420
Self-efficacy	-.808	.591	1.867	1	.172	.446
Test anxiety	.621	.367	2.861	1	.091	1.861
<u>Metacognitive awareness</u>						
Monitoring	-.002	.640	.000	1	.997	.998
Planning	1.048	.567	3.415	1	.065	2.853
Information management strategies	.578	.708	.666	1	.414	1.782
Declarative knowledge	-.187	.686	.074	1	.786	.830
<u>Epistemological beliefs</u>						
Innate knowledge	-.387	.348	1.238	1	.266	.679
<u>Self-perception of learning task</u>						
Task interest	-.050	.213	.055	1	.814	.951
Task challenge	.393	.241	2.659	1	.103	1.482
<u>Achievement-related constructs</u>						
Posttest score	.239	.354	.454	1	.500	1.270
Confidence judgment	-.470	.391	1.443	1	.230	.625
Calibration	.124	.366	.116	1	.734	1.132
<u>Perceived math-related capabilities</u>						
Math anxiety	-1.898	.784	5.862	1	.015	.150
Perceived calculation ability	.209	.503	.173	1	.678	1.232
Perceived memory capability	.077	.795	.009	1	.923	1.080

Table 12 shows two results. First, predictors in the full model can predict group membership at $\alpha=.016$, $\chi^2 (17, N=75) = 31.83$. Second, four independent variables – test anxiety ($p=.091$), planning ($p=.065$), and math anxiety ($p=.015$) – can statistically detect the patterns of self-reported study time allocation. Table 13 displays the distribution of the three statistically detectable predictors across the two categories of targets selection

for restudy. The participants who scored high on both test anxiety and planning recalled that they tended to select the not well learned targets for restudy. Those who self reported selecting targets judged not well learned scored lower on math anxiety than those who self-reported selecting other kinds of targets for restudy.

It can be concluded that except for the planning variable, personal factors underlying self-reported offline metacognition are different from those underlying actual online metacognition. Does this difference imply different cognitive bases for these two types of metacognition? This is an issue needing further investigation.

Table 13.

The means and Standard Deviations of the Variables Associated with the Self-reported Patterns of Item Selection for Restudy (N=75)

	Selecting Difficult Targets	Selecting Other Targets
Test anxiety	3.43(1.19)	3.15(1.42)
Planning	4.72(.77)	4.19(.99)
Math anxiety	2.21(.62)	2.47(.76)

When a parallel multivariate logistic regression was conducted on the sample of 60, the null hypothesis was not rejected at $\alpha = .18$, $\chi^2 (17, N=60)=22.07$, and no single predictor was found to statistically detect participants' patterns of self-reported study time allocation (all $p > .10$) that are shown in Table 14.

Table 14.

Results of the general multivariate Logistic Regression on self-reported Pattern of Restudy Time Allocation - Binary Classification Sample (N=60)

Model						
χ^2	df		<i>p</i>			
22.070	17		.182			
<u>Parameter Estimates</u>						
Predictors	B	S.E.	Wald	df	<i>p</i>	Exp(B)
<u>Motivation</u>						
External goal orientation	.190	.455	.175	1	.676	1.210
Task value	-.669	.573	1.363	1	.243	.512
Self-efficacy	-.551	.561	.964	1	.326	.576
Test anxiety	-.066	.393	.028	1	.867	.936
<u>Metacognitive awareness</u>						
Monitoring	.677	.673	1.014	1	.314	1.968
Plan	1.020	.669	2.326	1	.127	2.774
Information management strategies	-.187	.802	.054	1	.816	.830
Declarative knowledge	-.134	.795	.028	1	.866	.874
<u>Epistemological beliefs</u>						
Innate knowledge	-.581	.418	1.929	1	.165	.559
<u>Self-perception of learning task</u>						
Task interest	-.115	.229	.252	1	.616	.891
Task challenge	.438	.290	2.280	1	.131	1.549
<u>Achievement-related constructs</u>						
Posttest score	.357	.442	.652	1	.420	1.429
Confidence judgment	-.108	.545	.039	1	.843	.898
Calibration	.380	.499	.581	1	.446	1.462
<u>Perceived math-related capabilities</u>						
Math anxiety	-.348	.705	.244	1	.621	.706
Perceived calculation ability	-.151	.677	.050	1	.823	.859
Perceived memory capability	.381	.993	.147	1	.701	1.464

Summary

This chapter presented three sets of the outcomes based on statistical analyses of raw data obtained from self-report surveys, posttest, and the unobtrusive records about learners' online judgments of learning and time allocated for restudying target information. The findings converge on three aspects.

First, participants could be classified into two categories – a group spending more restudy time on targets judged not well learned targets versus a group spending more restudy time on targets judged well learned (i.e., either well learned or very well learned targets). Among these 75 participants, 37 allocated more restudy time to the targets they judged not well learned, and 38 people allocated more restudy time to targets they judged well learned. This result does not align with the discrepancy-reduction model proposed by Dunlosky and Herzog (1998) which claims that learners allocate more study time to difficult information.

Second, the multivariate logistic regression analyses under various circumstances lend credibility to the claim that three influential personal factors share variance with the relation between people's judgments of learning and restudy time allocation. These individual differences are monitoring, test scores, and calibration. These targets represent two categories of learner characteristics: metacognitive awareness and achievement-related factors. Two motivational variables, external goal orientation and task value also can statistically detect the patterns of restudy time allocation in the binary classification. Although this finding is not as robust as the preceding ones, it still merits further investigating since it empirically links motivational beliefs to metacognition which has been rarely studied in SRL and metacognition research.

Third, 19 of 45 subjects (42%) who recalled they selected difficult targets for restudy actually allocated more restudy time to targets without this characteristic. Meanwhile, 36% (11 out of 30) of those who recalled they selected for restudy targets rather than ones they judged difficult actually allocated the most restudy time to the targets not well learned. More importantly, it was found that personal factors underlying

self-reported metacognitive control operations are fundamentally different from those underlying their observed, on-the-fly metacognitive control. For example, in online metacognitive control, two context-dependent variables (or process variables), test scores and calibration, are statistically detectably associated with the classification of restudy time allocation pattern. However, the data show these two individual difference variables are not statistically detectably associated with the classification of self-reported restudy time allocation. Rather, self-reported restudy time allocation was statistically detectable mainly by one metacognitive awareness variable, planning; one motivational variable, test anxiety; and math anxiety. All are less context-specific than task interest, test scores and calibration.

Chapter 5

Discussion and Conclusions

What do the empirical findings of this exploratory study offer to enrich current knowledge about SRL, particularly regarding relations among metacognitive monitoring and control; and self-reported metacognition, motivation, personal epistemology and other individual differences? This chapter will discuss these findings organized according to the sequence of the findings presented in chapter 4.

Modification of the Discrepancy-Reduction Model

Models of self-regulated learning (SRL) research propose that (a) metacognitive monitoring and control play vital roles in SRL, (b) self-regulating learners are theorized to frequently monitor their state of learning against goals they set for themselves, and (c) productive regulation of studying relies on accurate metacognitive monitoring. If learners are not able to accurately differentiate well-learned material from not well-learned material, only by chance could they (a) avoid wasting time studying material that is already well learned and (b) allocate resources (i.e., selective attention, study time) to restudying what has not yet been adequately learned. Thus, a critical study strategy for learners is developing means for making accurate judgments of learning.

The adaptive relationship between metacognitive judgment and control in this view of SRL is expressed in Dunlosky and Hertzog's discrepancy-reduction model (1998) according to which learners allocate more time to not well learned information than to well learned information. This study's results do not support this model. Eye tracking data revealed that among 75 participants, on average 37 allocated more restudy time to

information judged not well learned while 38 allocated more restudy time to information they judged well learned (Table 6, Chapter 4). Among the 60 participants who distinguished 3 levels of JOLs, 27 allocated most restudy time to not well learned information, 20 participants allocated most restudy time to well learned information, and 13 participants allocated most restudy time to very well learned information.

Why doesn't the discrepancy-reduction model fit these empirical data? How should these findings be interpreted? Answers can be partly found in a comparison of the contexts and methods for measuring metacognitive judgments and control in this study versus others. To make this case, I briefly recap characteristics of the materials used to measure metacognition in the literature, and then probe accounts for why empirical findings in the present study do not align with the discrepancy-reduction model.

Almost all existing studies on metamemory that explored relations between metacognitive judgment and control, except for studies focusing on metacomprehension of text, used paired-associate lists as learning materials (Thiede & Dunlosky, 1999; Dunlosky & Thiede, 2004; Koriat, Ma'ayan, & Nussinson, 2006; Son & Sethi, 2006). For example, Dunlosky and Thiede (2004) employed 30 noun-noun paired associates consisting of two types of pairs: concrete-concrete pairs (e.g., dog-spoon) and abstract-concrete pairs (e.g., democracy-gravity). Computers in that experiment displayed the contents and controlled the procedure, as well as recorded the participants' responses. Like my experiment, Dunlosky and Thiede's experiments were composed of two study phases: study and restudy. During the period of restudy, two formats for displaying information were investigated: sequential versus simultaneous. In the simultaneous format, all of the 30 paired associates were randomly displayed simultaneously in a 3×10

array in which each cell was filled by one item. When the participants selected a pair for restudy, they typed the number of the corresponding cell then the selected item was deleted from the array. In the sequential format, participants selected contents for restudy one at a time. The other aforementioned studies differed in terms of constraints and procedures for presenting information but shared one critical aspect – all used paired associates as learning materials on which judgments of learning were made.

In contrast to materials used in the majority of metamemory research, the nature of metacomprehension requires researchers to use expository texts as learning materials. Rather than a paired-associate unit, participants in metacomprehension research made JOLs about an entire paragraph of text or several paragraphs comprising a whole text (Son & Metcalfe, 2000; Willey et al., 2005; Dunlosky & Lipko, 2007).

A sharp contrast between metacomprehension research and metamemory research lies in the form of learning materials used. The accuracy of metacognitive monitoring of metacomprehension is much lower than JOLs about paired associates (Willey et al., 2005); specifically, accuracy in monitoring one's level of understanding is usually quite poor. Accordingly, it can be theorized that memory for individual pairs of unrelated words is, in this respect, psychologically distinct from comprehension of coherently organized concepts, propositions, and schemas in texts.

On this logic, the discrepancy-reduction model grounded in research using paired associates does not account for results obtained in this study where participants studied a coherent text having both a microstructure and macrostructure and metacognitively monitored targets that were conceptually interrelated propositions in the text (see Figure 1, Chapter 3).

The vast majority of studies testing a discrepancy-reduction model employed paired-associates as learning materials that basically involved measurements of metamemory at a surface level according to Kintsch's theory (1998). According to Wiley et al. (2005), the structural complexity of a text plays an important role in determining the extent to which the surface and text-base levels differ from the situation level of comprehension that incorporates implicit logical and causal relations among ideas. Since lists of paired-associates and simple linear texts lack implicit relations between ideas, memory is not distinct from comprehension. As a result, metamemory-based regulation of study should differ from metacomprehension-based regulation of study time allocation. The next section will discuss the effects of learners' personal factors found in the present study on the variation of regulation of study effort – reading time allocation for restudy.

Personal Factors Moderating the Effect of Judgments of Learning on Regulation of Restudy Time Allocation

In chapter 4 the multivariate logistic regression analyses revealed that several individual difference variables can statistically detect differences among participants' JOLs and patterns of restudy time allocation (Tables 7 and 8). Depending on whether a binary or a trinary classification was considered, as many as 9 individual difference variables can statistically detect these patterns. Three personal factors – monitoring, test scores (actual cognitive performance), and calibration (i.e., accuracy of subjective judgment in cognitive performance) – were common to both binary and trinary classifications. These conceptually fall into two categories of learner characteristics: metacognitive awareness and achievement-related factors.

Before discussing the relation between metacognition and these two categories of individual difference variables, I first examine the role of motivation in metacognitive control even though motivation did not repeat as a predictor in both classifications.

Motivation and Metacognitive Control Operations

Results presented in Table 7 indicate that external goal orientation and task value can statistically predict group membership defined by the binary classification of JOLs. To my knowledge, this is the first evidence of a relation between self-reported motivation and observed online metacognition. Concisely, participants who rated themselves having high external goal orientation allocated more restudy time to information judged well learned. Those self-rating high on task value allocated more restudy time to targets judged not well learned. As discussed in Chapter 2, goal orientations are defined as the purposes for engaging in cognitive behaviors (Schunk et al., 2008). They not only refer to the purpose or reason for achievement but reflect a standard by which learners judge the success or failure of their cognitive engagement.

In Chapter 2, I put forth a question: If goal orientations serve as standards in guiding selective attention, what are the implications of this motivational construct for metacognition, since regulation of cognitive processing such as allocating study time essentially concerns people's selective attention? In the MSLQ (Duncan & McKeachie, 2005), items reflect external goal orientation as the purpose for attaining high grades and others' approval. Task value is measured as judgments of how interesting, useful, and important the learning task is to a participant. How did these standards guide participants' metacognitive control operationalized as restudy time allocation?

Participants who desire to attain a high grade or external approval from others allocated attention to information units they judged well learned presumably because they believed it was not necessary to actively focus on difficult content to obtain a high mark or please others in the context of the experiment. In fact, the learning task in the experiment had nothing to do with their academic records in their own studies. This finding aligns with the conclusion drawn by most studies on the effects of student motivation on strategy use in learning, that is, that intrinsic goal orientation predicts deep processing while extrinsic goal orientation is primarily associated with surface processing in learning (Pintrich, 2003; Schunk, et al., 2008). Spending less time on information that is judged to need more restudy time suggests a tendency of surface processing. In contrast, task value essentially represents an intrinsic motive. This is why those with high task value scores allocated more restudy time to information judged not well learned, indicating a tendency toward deep processing in learning.

Association between Metacognitive Awareness and Metacognitive Behaviors

Participants who achieved higher scores on monitoring allocated more restudy time to targets judged not well learned than those who scored lower on monitoring. On the contrary, the participants who achieved higher scores on planning allocated less restudy time to targets judged not well learned than those who scored less on planning. This suggests participants' metacognitive control is guided not only by online, immediate metacognitive judgments but also by their perceived metacognitive skills for regulating cognition. In the Metacognitive Awareness Inventory (MAI; Schraw & Dennison, 1994), metacognitive awareness is composed of two components: knowledge about cognition and regulation of cognition. Both monitoring and planning belong to the category of

regulation of cognition. For example, questions in the inventory related to monitoring include “I periodically review to help me understand important relationships,” “I ask myself questions about how well I am doing while I am learning something new.” As for planning, questions include “I organize my time to best accomplish my goals,” and “I pace myself while learning in order to have enough time.” My results show that participants who rated themselves higher on these metacognitive skills tended to spend more time restudying than those that rated themselves lower in these skills. An inference is that, for those holding beliefs they have strong metacognitive skills, concentrating on not well learned information when restudying is presumably a pre-set metacognitive tactic. This will be tested in the examination of the personal factors underlying self-reported (postdictive) metacognitive control discussed in the subsequent sections.

This finding also invites a distinction between self-reported, schematized metacognitive awareness/knowledge and observed, online metacognitive behaviors in learning. In essence, the former is general, stable, and context-independent – an aptitude, – whereas the latter is specific, transient, and context-dependent – an event (Winne & Perry, 2000). Winne and Perry’s notion of event is similar to the notion of metacognitive experience in the framework of Efklides’ research (2006). According to Efklides, metacognitive experiences refer to learners’ online feelings, judgments, thoughts, and responses to the task during task processing. In my opinion, it is an expression of SRL as process in Winne’s model of SRL. Efklides also pointed out that the distinction between trait-like characteristics of the person and online responses to the task at hand is critical for our understanding of the formation of subjective experiences and their interaction with the features of the task.

In closing, the finding associating individuals' metacognitive awareness to their observed, actual metacognitive control is significant finding for metacognition and SRL research. Not only does it lead to modifying the dominant discrepancy-reduction model of metacognition; it also invites us to think about relationships between people's general, schematized metacognitive awareness/knowledge in long-term memory and their actual, on-the-fly metacognitive behaviors in a SRL process.

Associations of Metacognition with Cognitive Achievement and Calibration of Achievement

The Role of Cognitive Achievement in Metacognitive Control

In both binary and trinary classifications of restudy time allocation, scores on the posttest can statistically detect the patterns of restudy time allocation. The group that allocated more restudy time to information judged not well learned achieved a higher mean test score than the group that allocated more restudy time to information judged well learned. This finding associates cognitive performance with regulation of cognition. Although in the regression model, the test score is treated as predictor and the pattern of restudy time allocation is the outcome variable, the logical relationship between them actually is reversed. Since this study did not measure individuals' prior knowledge of the content studied, it is impossible to assess whether prior domain knowledge guided their allocations of restudy time. This is one of the limitations of this research.

However, this finding at least empirically links learners' domain knowledge to their online regulation of learning, in line with Winne's view (1996) that individual differences in domain knowledge influence the degree to which students deliberately self regulate their learning. Specifically, the less extensive one's domain knowledge is at the time of study (or restudy), the greater the need to exercise self-regulation of study

strategies and tactics while engaging in complex learning tasks. This idea can more or less explain why participants with lower test scores tended to allocate more reading time to information they judged not well learned. The aforementioned finding that higher scores on metacognitive awareness predicted greater time allocated to restudy of information judged not well learned seems aligned with deliberate SRL processes.

The Role of Calibration in Metacognitive Control

Among the three variables that consistently statistically detected patterns of restudy time allocation, calibration is the most unique in this study because it is the only latent construct formed as a combination of two observed variables, achievement and confidence judgment regarding achievement. The findings from both classifications of restudy time allocation converge – the patterns of restudy time allocation are strongly statistically detectable by calibration. Those who allocated more restudy time to information judged not well learned were poorer calibrators compared to those who allocated more restudy time to information judged as well learned. Two basic issues will be discussed about this finding. First, what is the nature of calibration? Second, how does this latent variable, calibration, help us theorize about the relation between metacognitive monitoring and control from the perspective of the dual-character of SRL?

Calibration – accuracy of self-judgment of cognitive performance – is a facet of metacognitive ability. The association of calibration with patterns of restudy time allocation suggests that calibration essentially fuses four psychological processes: metacognitive judgment of learning (JOLs), metacognitive control (restudy time allocation), cognitive achievement, and judgment of achievement in relation to a particular test item and context. The first two processes occurred during studying while

the last two processes occurred during the posttest. What does this finding imply for our further understanding of the nature of metacognitive monitoring and control, and the relationship between them?

To address this issue, first consider the nature of calibration. As discussed earlier, calibration is operationally defined as a combination of cognitive judgment and actual test performance. Kröner and Biermann's research (2007) shows that confidence judgments are general and stable; they are a trait or, in Winne and Perry's (2000) terms, an aptitude. Kröner and Biermann found that confidence judgments are strongly associated with task-general self-concept, a theory/belief-driven individual variable. In contrast, test performance, one of the two constituents of calibration, is task-dependent and data-driven. Taken together, calibration therefore combines both theory/belief-driven and data-driven features. What are the implications following from this hypothetical dual-process view of calibration for theorizing about online metacognition while studying and restudying?

I found that participants' on-the-fly metacognition was predicted by two general, offline metacognitive awareness variables: task-specific test performance and calibration of the performance. This implies that individuals' on-the-fly metacognition may be a dual-process as well: theory/belief-driven (e.g., general metacognitive awareness) and data-driven (e.g., online JOLs). If online metacognition within SRL can be regarded as a dual-process, this implies the same dual-character nature for SRL. This will be further examined in the next section.

Comparison and Contrast between Self-Reported Metacognition and Actual Online Metacognition

There is a need to explore the relationship between real-time, online metacognitive judgments and control in the context of SRL. The preliminary conclusion deriving from the discussion thus far is that online metacognition incorporates both theory/belief-driven processes and data-driven processes. This can be further illustrated by comparing and contrasting participants' actual, online metacognition, measured by trace data and eye tracking in this study, with self-reported (recalled) metacognition measured in the retrospective report.

Participants' metacognitive control was assessed in two ways in this study. One is the traditional method by which each participant was required to recall in the post-experiment survey how they allocated reading time in the restudy phase. Self-report surveys have been the main method used in the literature for probing the use of cognitive and metacognitive strategies, and their relationship with other personal factors such as motivation and epistemological beliefs in SRL processes. The second method was using unobtrusive traces recorded in gStudy augmented by eye tracking data that revealed how participants actually regulated their studies in real time. What follows is an overview of the two key findings emerging from these methods for collecting data.

First, there was considerable disparity between what learners self-reported and what they actually did in allocating reading (gaze) time during restudy (Table 11). Specifically, 19 out of 45 participants (42%) who recalled they selected for restudy information judged difficult actually allocated most restudy time to other kinds of contents. Meanwhile, 36% (11 out of 30) of those who recalled they selected information judged other than difficult actually allocated most restudy time to that information.

The time interval between the restudy phase in the experiment and the point in time when the participants recalled how they restudied was about 10-20 minutes. Why could not the participants report accurately how they strategically studied? This discovery is aligned with Perry and Winne's claims (2006) about the limitations of self-report measures on learners' perceptions about how they actually study: "Learners often are not very accurate at calibrating thought and action" (p. 215). This finding further demonstrates that the gStudy and eye tracking technologies used in this study play a crucial role in overcoming limitations of self-report measurement that have been widely applied in psychology.

The second finding is that the personal factors underlying recalled metacognitive control are not the same as those underlying the actual metacognitive control. Specifically, the multivariate logistic regression model shown in Table 12 identifies that three individual difference variables can statistically detect the patterns of self-reported restudy time allocation (metacognitive control): test anxiety (motivational variable), planning (metacognitive awareness), and math anxiety. Table 13 displays the means of these predictors across the two patterns of self-reported restudy time allocation. Among the 75 participants, those who recalled they allocated more restudy to information judged not well learned scored higher on both test anxiety and planning, and lower on math anxiety.

In my discussion on the influence of people's general metacognitive awareness on their online metacognitive control, I hypothesized that concentrating on information judged not well learned for restudy is presumably a pre-set metacognitive strategy. Supporting this hypothesis is the finding that people with high scores on planning, a

general metacognitive awareness variable, tended to self report they allocated more restudy time to information judged not well learned. A high score on planning suggests a high degree of deliberation regulating one's cognitive processing, including allocation of study/restudy time. Thus, the association between self-reported metacognitive awareness and allocating more restudy time to information judged not well learned implies a conscious, deliberate process regarding restudy time allocation.

Unlike actual online metacognition, planning is the only aptitude factor that statistically detects the patterns of self-reported metacognition. This finding suggests that different personal factors and psychological processes underlie these two reflections of metacognition. Also, the finding that the pattern of self-reported metacognition is not statistically associated with test performance (a data-driven process) and calibration (a combination of theory/belief-driven and data-driven) implies that self-reported metacognition is possibly completely theory/belief-driven unlike the online metacognition which associated with both a learner's theory/beliefs and data to which the learner attends.

Why is metacognitive awareness theory/belief-driven rather than data-driven? Metacognitive knowledge measured by the metacognitive awareness questionnaire essentially represents respondents' general and stable metacognitive strategies under general circumstances (Schraw, 1997). The association between self-reported restudy time allocation and general metacognitive awareness (planning) can be viewed as a signature of theory/belief-driven metacognitive regulation. Therefore, it can be inferred that what self-reported metacognition measured essentially represents the aptitude respect of SRL. In contrast, people's online metacognition is modeled as a dual-process, theory-

driven plus data-driven, corresponding to the dual-character of SRL as aptitude and process. This is a significant conclusion of this study.

Why did 42% of participants who recalled they selected difficult information for restudy allocate most restudy time to other information they judged was not difficult? In my view, people's imperfect calibration and memory should not be the only reason. Perry and Winne's theory (2006) summarized two threats to the validity of self-report survey instruments in measuring SRL as process: context and calibration. The contexts of both pre-experiment questionnaires (where metacognitive awareness was measured) and post-experiment questionnaire (where self-reported metacognitive control was assessed) varied from the context in which their online metacognitive control was actually exercised. In this sense, my inference from the view of theory-based metacognitive regulation is that when participants recalled how they allocated study time in learning, their memory was very likely occupied by a combination of a recall of how they did while studying and the enduring and stable metacognitive strategies in the similar situations. This is why the patterns of recalled metacognitive control can be statistically detectable only by self-reported metacognitive awareness. Therefore, a basic conclusion is that learners' self-perception of their metacognitive processes is inferential and theory-driven while learners' actual on-the-fly metacognitive processes combine transient data-driven and theory-driven.

Another account for the view about the inferential, theory-based nature of self-reported metacognitive control resides in the important tenet in contemporary cognitive psychology (Brunning et al., 2004) about the nature of encoding and retrieval process: memory is an inferential process involving reconstruction of information. That implies

that “postdicting” metacognitive control is a reconstructive process which is presumably guided by prior experiences as well as general knowledge. This can account for why self-reported control is strongly associated with metacognitive awareness, which implies an inferential, theory-directed process. At least, it can be assumed that participants’ general metacognitive knowledge played a role in formulating their recollections about their regulation of study time and effort while restudying.

Koriat et al. (2006) proposed two general modes describing the temporal relation between metacognitive monitoring and control: sequential and simultaneous. In the sequential mode, monitoring and control alternate in a cascading pattern which leads to a dual-process model of the relationship between metacognitive monitoring and control: monitoring-based control (MC) and control-based monitoring (CM). For instance, the discrepancy-reduction model is an illustration of MC processing according to which control follows along in the wake of monitoring. Conversely, in the CM process, the feedback from a control operation serves as input for later monitoring. Koriat et al. further claimed that students’ metacognitive regulation essentially involves both goal-driven and data-driven regulation in many real-life situations. This study empirically supports this idea.

Taken together, there are at least three implications of these findings. First, the cognitive mechanism generating learners’ self-perception about how they studied in an earlier study session is qualitatively different from cognitive processes that determine how they actually study. Second, self-reported metacognitive control is associated with an individual learner’s general study strategies that represent relatively trait-like, enduring psychological properties. This was the planning variable in this study. Third,

real-time, actual metacognitive control operations are guided by both theory/goal-driven and experience/data-driven factors. These inferences are consistent with Perry and Winne's theory (2006) that learners in self-report largely rely on heuristics to estimate properties of their cognitive engagement.

The data-driven regulation of cognition corresponding to experience-based processes taps an implicit/unconscious feature of metacognition in SRL. We still know little about this aspect of SRL processes. Exploring implicit cognition/learning is one of three major emerging strands of research in the learning sciences (Bransford, Barron, Pea, Meltzoff, Kuhl et al., 2006). In this study, comparison and contrast of the underlying personal factors between learners' self-perception of their metacognitive processes and their actual metacognitive operations leads us to deepen and enrich existing knowledge about mechanisms of metacognitive control. The discrepancy between them seems to be due to methods that were used to measure these variables, but essentially can be ascribed to the different personal factors underlying them. The former is related to a methodological issue as to measuring metacognition and SRL; the latter taps a theoretical issue for conceptualizing them. It can be concluded that whether SRL manifests as aptitude or event/process depends heavily on the approach employed, and most current studies that relied on self-report survey instruments only informed the aptitude side of metacognition. To systematically investigate the event/process side of SRL, researchers need to make full use of the advanced learning technologies such as gStudy and eye tracking systems to unobtrusively collect accurate trace data about learners' actual cognitive and metacognitive processes. This is one of the significant implications of this study for the future research in SRL and metacognition.

Dual-Process Character of Metacognition and the Notion of Agency

Why is the dual-process character of metacognition is so important for theorizing the nature of SRL processes? In Chapter 2, it was stated that self-regulated learning theories are inherently built on a fundamental meta-theoretical tenet – human agency. In Bandura’s social cognitive theory, the agency concept refers to an emergent capability of individual human beings to make choices and to act on these choices (Bandura, 2001, 2006). Individuals’ power to originate actions for a given purpose is constituted primarily through interaction between brain activities and sociocultural contexts. Bandura further points out that “Cognitive agents regulate their actions by cognitive downward causation as well as undergo upward activation by sensory stimulation.” (2001, p. 4-5).

Dual-process online metacognition as a whole seems to be an expression of this notion of emergent interactive agency. General, schematized metacognitive awareness/knowledge, on one hand, essentially represents the aspect of cognitive top-down causation (theory-driven) in self-regulation of cognitive processes (e.g., allocation of study/restudy time). The labeled information units embedded in the text as targets for JOLs in this study, on the other hand, can presumably function as bottom-up (data-driven) activation in formulating those empirically observed metacognitive control operations. To my knowledge, this is one of the very few studies in the literature yielding empirical data that witness the two interactive processes of this theoretical construct – agency.

Last but not least, the idea of dual-process metacognition can help us make better sense of the nature of self-regulated learning. Let us regress to a fundamental question that researchers have asked since the emergence of SRL theories and research two decades ago – What is SRL? Zimmerman (2001) claims that “Neither a mental ability nor

an academic performance skill, self-regulation refers instead to the self-directive process through which learners transform their mental abilities into task-related skills.” (p. 1). Given that individuals’ general, schematized metacognitive awareness can be viewed as a trait-like, enduring aptitude or mental ability, actual metacognition as a self-directive process presumably realizes the transformation of the mental ability (e.g., planning and monitoring one’s mental processes) into self-regulatory skills (e.g., skills in allocating study/restudy time – cognitive resources). In this sense, the dual-process character of metacognition essentially reflects the nature of the SRL construct. This is why the idea of the dual-process metacognition is a significant finding of this study.

Conclusions

Two basic findings of this study were: (1) the relation between metacognitive judgments and control in SRL is complex, and (2) this relation is associated with student motivation, personal epistemology, metacognitive awareness, and other personal psychological factors. The relationship between individuals’ JOLs and allocations of restudy time are not as simple and linear as the discrepancy-reduction model predicts. Specifically, not all participants allocated more restudy time to information they self judged to be difficult to learn; instead, some allocated more restudy time to information they judged was well learned.

However, the preceding discussion has shown that the second finding is not as straightforward. The answer to whether the relation between metacognitive judgments and control is associated with individual differences depends on how metacognition is measured. This study employed two approaches to assessing metacognitive processes. One was real-time metacognitive judgments in the form of JOLs measured in the initial

study plus an indicator or metacognitive control operationalized as restudy time allocation recorded unobtrusively by an eye tracking system. The second approach measured metacognition by what individual participants recalled in the retrospective survey about how they allocated their reading time to restudy the different kinds of information. The former is called online or on-the-fly metacognition; the latter is called self-reported or aggregated metacognition. When drawing conclusions in relation to the second hypothesis, this distinction matters.

After analyzing the dual-process nature of calibration and its association with the effect of online metacognitive judgments on metacognitive control, a third preliminary conclusion is that the relationship between real-time, online metacognitive judgments and control combines a theory/goal-driven process and data-driven process. Learners' regulation of study time and effort is shaped by both online JOLs plus general and stable personal factors such as general metacognitive awareness. This dual-process feature of online metacognition empirically illustrates the dual-character of SRL as both trait-like aptitude and event/process. This third conclusion might be the most significant in this study.

Fourth, the comparison between the participants' real-time, online metacognition and their self-reported/recalled metacognition measured after learning further supports the preceding conclusion. Self-reported/recalled metacognition is basically inferential and theory/belief-driven.

Finally, opportunity to uncover these conclusions was afforded by using advanced learning technologies such as gStudy and an eye tracking system to unobtrusively collect accurate trace data about learners' indexing cognitive and metacognitive processes. Using

these innovative techniques and methods meets Zimmerman's call for "the second wave of research, which has involved the development of online measures of self-regulatory processes" (2008, p. 166).

Limitations and Future Research

The limitations of this dissertation research can be classified into two sets: intrinsic deficiencies of the research design, and measurement errors perhaps due to early uses of state-of-the-art technologies. These limitations plus hypotheses emerging from this work provide a foundation for follow-up studies about re-conceptualizing and re-operationalizing current SRL theories and research.

One deficiency in the current design might be that there was no pretest of content to be learned in the experiment. As a result, it is impossible to examine the effect of students' prior knowledge on the control function of metacognition in SRL processes when examining the effect or interactions with personal factors on the dependent variable. The original rationale for not administering a pretest was to avoid contaminating participants' judgments of the targets to be learned by providing opportunity to make those judgments in the course of answering pretest items. However, the interpretive power of the data might be stronger if the prior knowledge could have been assessed. For example, when explaining why test scores played a vital role in discriminating participants' patterns of metacognitive control, the pretest might help account for the role, if any, of individuals' prior knowledge in this regard.

Another limitation in this study may arise due to errors in measuring reading (gaze). The validity of measuring the relation between JOLs and restudy time allocation almost totally depends on the accuracy of computing the gaze time each individual spent

in the target areas when restudying. Thanks to Dr. Campbell's advice in this regard, several measures were taken prior to the experiment to maximize the accuracy of eye tracking data, for example, enlarging the font size, increasing spacing between words and lines in the reading material, strictly controlling the calibration procedure, standardizing the after-experiment data processing, and so on. However, in any case, relying on eye tracking data in measuring the dependent variable does introduce some risks.

Besides the above limitation in relation to the use of eye tracking system, the possible dissociation between where a learner gazes at information and what he or she thinks about with regard to that information is an inevitable issue with regard to the validity of measuring cognition while restudy. Although Isaacowitz's claim (2006) that gaze fixations match the target of visual attention, it must be acknowledged that totally equating gaze time measured during restudy with the cognitive processes is inferential.

Finally, this was a laboratory-based study. Future research would add to knowledge about students' self-regulatory capabilities if the issues researched here could be investigated in authentic learning contexts.

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Appendix 1

General Bivariate Correlations among the 17 Predictors in the Multivariate Logistic Regression Models

Table 15a. The Shorthand of Each Predictor

Predictors	Letters
Extrinsic goal orientation	EG
Task value	TV
Self-efficacy	SE
Test anxiety	TA
Monitoring	MO
Planning	PL
Information management strategies	IM
Declarative knowledge	DK
Innate knowledge	IK
task interest	TI
task challenge	TC
test score	TS
confidence judgment	CJ
Calibration	CA
math anxiety rating	MA
confidence in reading and recall	CR
confidence in calculation	CC

Table 15b. General Bivariate Correlations of the 17 Predictors in the Multivariate Logistic Regression Models

	EG	TV	SE	TA	MO	PL	IM	DK	IK	TI	TC	TS	CJ	CA	MA	CR
TV	.70															
SE	.36	.54														
TA	.40	.12	-.20													
MO	.17	.20	.43	.07												
PL	.12	.19	.34	-.04	.62											
IM	.11	.10	.31	.01	.64	.58										
DK	-.05	.17	.50	-.29	.34	.51	.54									
IK	.01	-.08	-.18	.01	-.06	-.01	-.16	-.18								
TI	.24	.26	.08	.02	-.10	-.11	.00	-.16	-.03							
TC	-.02	-.10	-.42	.14	-.14	-.05	-.03	-.06	.05	.09						
TS	-.03	-.18	-.10	.01	-.06	.11	-.07	-.14	.02	-.10	-.09					
CJ	.20	.36	.57	-.17	.38	.21	.22	.21	-.02	.12	-.56	.08				
CA	.08	.22	.24	-.09	.07	-.13	.05	.15	.06	.14	-.19	-.67	.36			
MA	.12	-.05	-.37	.38	-.32	-.31	-.21	-.29	-.02	-.11	.28	-.01	-.34	.02		
CR	.14	.22	.61	-.09	.38	.29	.22	.33	-.28	-.02	-.35	.04	.43	.11	-.34	
CC	.11	.04	.24	-.03	.14	.04	.04	.10	-.15	.05	-.19	.18	.33	-.06	-.17	.45

Appendix 2

Consent to Participate in Educational Psychology Research

Principal investigator: Mr. Li Sha (PhD student)

Application number: 38012

email: lsha@sfu.ca

Senior supervisor: Dr. Phil Winne

email: winne@sfu.ca

Tel: 604-291-4858

Co-investigator: Dr. Stephen Campbell

email: sencael@sfu.ca

Tel: 604-291-3630

Place: Education Building 7504, Educational Neuroscience Laboratory (ENGRAMMETRON), Faculty of Education, Simon Fraser University

Time: June-August 2007

Study title: Dynamic and complex relation between metacognitive judgment and metacognitive control in self-regulated learning

1. Purpose

This PhD dissertation research investigates whether your motivation, beliefs about what knowledge is, and other factors influence the relation between judgments of learning and content you study again. It will enrich our knowledge about metacognitive monitoring and metacognitive control in self-regulated learning. We also will use eye tracking technology to record what you look at when you study.

2. Potential risks

There is no risk at all to participating in this research. You should know that the eye tracking technology will reflect very low levels of infrared light off the retina in your eye but this can not be felt and it does not damage your eye in any way.

3. Procedures

First, you will fill out six questionnaires. Second, I will teach you how to use a computer-based system while studying; it is called gStudy. Third, you will have about 10 minutes to study material about math with gStudy. Fourth, you will have about 10 minutes to restudy the material. Finally, you will take a test and participate in a very short retrospective interview about your experience. You may also be invited to participate in an educational neuroscience study conducted simultaneously with this study.

Time allocation

Questionnaires	Training	Study	Restudy	Test	Interview
35 min	5 min	10 min	10 min	10 min	10 min

80 min

add one more hour for preparation purposes if you choose to participate in the educational neuroscience study conducted simultaneously with this study

4. Confidentiality

You will be assigned an anonymous participant code to ensure your identity can never be connected to information about you. All email communications between you and the investigator will be under an undisclosed recipient's list. All questionnaire and test data will be stored in a locked file cabinet in Dr. Winne's lab. The data about how you study that gStudy records and about where you look that the eye tracking technology records will be automatically saved on secure (password protected) computers that are located in Dr. Winne's lab. Only the principal investigator, co-investigator, system administrator, and members of the supervisory committee can read this information. Unless you provide separate permission not to, the data collected in this study will be destroyed five years after this research has finished. You can contact Mr. Li Sha, Dr. Phil Winne, and Dr. Stephen Campbell for research results. All the results along with the raw data will be stored in a locked file cabinet in Dr. Winne's lab.

5. Participant rights

You can withdraw from this study at any time and for any reason with no explanation required, and this will have no effect whatsoever on your status at SFU. Your payment of \$20 for participating in this study will be provided only if you complete all the activities in the experiment.

CONSENT TO PARTICIPATE IN EDUCATIONAL PSYCHOLOGY RESEARCH

Principal investigator: Mr. Li Sha (PhD student)

Application number: 38012

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Senior supervisor: Dr. Phil Winne

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Tel: 604-291-4858

Co-investigator: Dr. Stephen Campbell

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Tel: 604-291-3630

Place: Education Building 7504, Educational Neuroscience Laboratory (ENGRAMMETRON), Faculty of Education, Simon Fraser University

Time: March-June 2007

Study title: Dynamic and complex relation between metacognitive judgment and metacognitive control in self-regulated learning

I understand I am being asked to participate in educational psychology research, and I understand the descriptions provided on page 1 and 2 about the procedures, possible risks, and the purpose of this research. Also, I understand that my participation is voluntary; I can stop at any time during the study. I understand all the data I provide will be anonymously and confidentially maintained, analyzed, presented, and published so that my identity will never be revealed to any person or agency.

I understand that when I have concerns and complaints I can contact Dr. Hal Weinberg, Director, Office of Research Ethics, at hal-weinberg@sfu.ca, or 778-782-6593.

I indicate my understanding and my willingness to participate in this research study by signing this informed consent form.

My email address: _____

Name (*print*)

Signature

Date

Participant's Feedback (optional)

Completion of this form is OPTIONAL. However, if you have served as a participant in a project and would care to comment on the procedures involved, you may complete the following form and send it to the Director, Office of Research Ethics, 8888 University Drive, Multi-Tenant Facility, Burnaby BC V5A 1S6, Canada. All information received will be strictly anonymous, unless you indicate below that you wish your name to be known.

Title of research study: Dynamic and complex relation between metacognitive judgment and metacognitive control in self-regulated learning

Principal Investigator Name: Li Sha

Investigator Department: Faculty of Education

Did you sign an Informed Consent Form before participating in the project?

Y No

Were there significant deviations from the originally stated procedures?

Yes No

If Yes, please describe the nature of the deviation, and the date, place and time:

Please make any comments you may have: _____

Completion of the Information below is Optional

Participant Last Name: _____ First Name: _____

Participant Contact Information/ Address: _____

Home Telephone: _____

Work Telephone: _____

Email: _____

Do you wish your feedback to be anonymous? Yes

Appendix 3

Advertisement of the Experiment

Participate in an educational psychology experiment and earn \$20

You are invited to participate in a computer-based educational psychology experiment. In this study, you will: fill out several questionnaires, study and reread material on number theory, take a short test and participate in a brief interview. You also can experience eye tracking technology that records how you scan the material as you study. The experiment will last about 70-90 minutes. You will be paid \$20 if you complete all activities in the experiment.

If you have interest, please contact Mr. Li Sha at lsha@sfu.ca

Appendix 4

Demographic Questionnaire

1. Gender
 - male
 - female
2. Language
 - First Language (first learned at home)
 - Second Language
 - Other(s)
3. Your current major at SFU (e.g., psychology, English, computer science, history, etc)
Answer :
4. What are the ethnic or cultural origins of your ancestors? (For example Canadian, English, French, Chinese, German, M 閩 is, Inuit, Lebanese, etc.)
Ethnicity (Please specify):
5. Highest degree completed
 - high school
 - undergraduate
 - master's
 - doctoral

Appendix 5

Motivation Questionnaire

The following questions ask about your motivation for and attitudes about this class. Remember there are no right or wrong answers; just answer as accurately as possible. Use the scale below to answer the questions. If you think the statement is very true of you, circle 7. If a statement is not at all true of you, circle 1. If the statement is more or less true of you, circle the number between 1 and 7 that best describes you.

	1	2	3	4	5	6	7
	not at all true of me						very true of me
1. In a learning task like this one, I prefer the material that really challenges me so I can learn new things.	1	2	3	4	5	6	7
2. If I study in appropriate ways, then I will be able to learn the material in this task.	1	2	3	4	5	6	7
3. When I take a test I think about how poorly I am doing compared with other participants.	1	2	3	4	5	6	7
4. I think I will be able to use what I learn in this task in others.	1	2	3	4	5	6	7
5. I believe I will receive an excellent grade in this task.	1	2	3	4	5	6	7
6. I'm certain I can understand the most difficult material presented in the readings for this task.	1	2	3	4	5	6	7
7. Getting a good impression in this task is the most satisfying thing for me right now.	1	2	3	4	5	6	7
8. When I take a test I think about items on other parts of the test I can't answer.	1	2	3	4	5	6	7
9. It is my own fault if I don't learn the material in this task.	1	2	3	4	5	6	7
10. It is important for me to learn the reading material in this task.	1	2	3	4	5	6	7
11. The most important thing for me right now is obtaining a good impression so my main concern in this task is getting a good grade in the test.	1	2	3	4	5	6	7
12. I'm confident I can learn the basic concepts presented in the reading material.	1	2	3	4	5	6	7
13. If I can, I want to get better grades in this task than most of the other participants.	1	2	3	4	5	6	7
14. When I take tests I think of the consequences of failing.	1	2	3	4	5	6	7

15.	I'm confident I can understand the most complex material presented in this task.	1	2	3	4	5	6	7
16.	In a learning task like this, I prefer learning material that arouses my curiosity, even if it is difficult to learn.	1	2	3	4	5	6	7
17.	I am very interested in the content area of this task.	1	2	3	4	5	6	7
18.	If I try hard enough, then I will understand the learning material.	1	2	3	4	5	6	7
19.	I have an uneasy, upset feeling when I take a test.	1	2	3	4	5	6	7
20.	I'm confident I can do an excellent job on this task.	1	2	3	4	5	6	7
21.	I expect to do well in this activity.	1	2	3	4	5	6	7
22.	The most satisfying thing for me in this task is trying to understand the content as thoroughly as possible.	1	2	3	4	5	6	7
23.	I think the learning material in this task is useful for me to learn.	1	2	3	4	5	6	7
24.	When I have the opportunity in this task, I choose the contents that I can learn from even if they don't guarantee a good grade in the test.	1	2	3	4	5	6	7
25.	If I don't understand the learning material, it is because I didn't try hard enough.	1	2	3	4	5	6	7
26.	I like the subject matter of this task.	1	2	3	4	5	6	7
27.	Understanding the subject matter of this task is very important to me.	1	2	3	4	5	6	7
28.	I feel my heart beating fast when I take a test.	1	2	3	4	5	6	7
29.	I'm certain I can master the knowledge in this task.	1	2	3	4	5	6	7
30.	I want to do well in this task because it is important to show my ability to my family, friends, employer, or others.	1	2	3	4	5	6	7
31.	Considering the difficulty of this task, and my skills, I think I will do well in this task.	1	2	3	4	5	6	7

Appendix 6

Metacognitive Awareness Inventory

This part of the inventory surveys your views of study strategies and how you use strategies. Using numbers between 1 and 7, write a number on the line that best corresponds to whether the statement is. **Remember there are no right or wrong answers; just answer as accurately as possible.**

0 = not true at all of you up to 7 = true of you

1. _____ I ask myself periodically if I am meeting my goals.
2. _____ I consider several alternatives to a problem before I answer.
3. _____ I try to use strategies that have worked in the past.
4. _____ I pace myself while learning in order to have enough time.
5. _____ I understand my intellectual strengths and weaknesses.
6. _____ I think about what I really need to learn before I begin a task.
7. _____ I know how well I did once I finish a test.
8. _____ I set specific goals before I begin a task.
9. _____ I slow down when I encounter important information.
10. _____ I know what kind of information is most important to learn.
11. _____ I ask myself if I have considered all options when solving a problem.
12. _____ I am good at organizing information.
13. _____ I consciously focus my attention on important information.
14. _____ I have a specific purpose for each strategy I use.
15. _____ I learn best when I know something about the topic.
16. _____ I know what the teacher expects me to learn.
17. _____ I am good at remembering information.
18. _____ I use different learning strategies depending on the situation.
19. _____ I ask myself if there was an easier way to do things after I finish a task.
20. _____ I have control over how well I learn.
21. _____ I periodically review to help me understand important relationships.
22. _____ I ask myself questions about the material before I begin.
23. _____ I think of several ways to solve a problem and choose the best one.
24. _____ I summarize what I've learned after I finish.
25. _____ I ask others for help when I don't understand something.
26. _____ I can motivate myself to learn when I need to.

0 = not true at all of you up to 100 = true of you

27. _____ I am aware of what strategies I use when I study.
28. _____ I find myself analyzing the usefulness of strategies while I study.
29. _____ I use my intellectual strengths to compensate for my weaknesses.
30. _____ I focus on the meaning and significance of new information.
31. _____ I create my own examples to make information more meaningful.
32. _____ I am a good judge of how well I understand something.
33. _____ I find myself using helpful learning strategies automatically.
34. _____ I find myself pausing regularly to check my comprehension.
35. _____ I know when each strategy I use will be most effective.
36. _____ I ask myself how well I accomplished my goals once I'm finished.
37. _____ I draw pictures or diagrams to help me understand while learning.
38. _____ I ask myself if I have considered all options after I solve a problem.
39. _____ I try to translate new information into my own words.
40. _____ I change strategies when I fail to understand.
41. _____ I use the organizational structure of the text to help me learn.
42. _____ I read instructions carefully before I begin a task.
43. _____ I ask myself if what I'm reading is related to what I already know.
44. _____ I reevaluate my assumptions when I get confused.
45. _____ I organize my time to best accomplish my goals.
46. _____ I learn more when I am interested in the topic.
47. _____ I try to break studying down into smaller steps.
48. _____ I focus on overall meaning rather than specifics.
49. _____ I ask myself questions about how well I am doing while I am learning something new.
50. _____ I ask myself if I learned as much as I could have once I finish a task.
51. _____ I stop and go back over new information that is not clear.
52. _____ I stop and reread when I get confused.

Appendix 7

Epistemological Belief

The following questions ask about your general epistemological belief. **Remember there are no right or wrong answers; just answer as accurately as possible.** Use the scale below to answer the questions. If you strongly disagree the statement, circle 1. If you strongly agree the statement, circle 7. If you more or less agree or disagree, circle the number between 1 and 7 that best describes you.

	1	2	3	4	5	6	7
	strongly disagree						very strongly agree
1.						1	2 3 4 5 6 7
2.						1	2 3 4 5 6 7
3.						1	2 3 4 5 6 7
4.						1	2 3 4 5 6 7
5.						1	2 3 4 5 6 7
6.						1	2 3 4 5 6 7
7.						1	2 3 4 5 6 7
8.						1	2 3 4 5 6 7
9.						1	2 3 4 5 6 7
10.						1	2 3 4 5 6 7
11.						1	2 3 4 5 6 7
12.						1	2 3 4 5 6 7
13.						1	2 3 4 5 6 7
14.						1	2 3 4 5 6 7
15.						1	2 3 4 5 6 7
16.						1	2 3 4 5 6 7
17.						1	2 3 4 5 6 7
18.						1	2 3 4 5 6 7
19.						1	2 3 4 5 6 7
20.						1	2 3 4 5 6 7
21.						1	2 3 4 5 6 7
22.						1	2 3 4 5 6 7
23.						1	2 3 4 5 6 7
24.						1	2 3 4 5 6 7
25.						1	2 3 4 5 6 7
26.						1	2 3 4 5 6 7
27.						1	2 3 4 5 6 7
28.						1	2 3 4 5 6 7

Appendix 8

Math Anxiety Rating Scale

Please rate your anxiety when you do the following things related to math.

1. Looking through the pages in a math text.
0 (no anxiety) 1 2 3 4 (high anxiety).
2. Having to use the tables in the back of a math book.
0 (no anxiety) 1 2 3 4 (high anxiety).
3. Thinking about an upcoming math test one day before
0 (no anxiety) 1 2 3 4 (high anxiety).
4. Watching a teacher work an algebraic equation on the blackboard.
0 (no anxiety) 1 2 3 4 (high anxiety)
5. Being told how to interpret probability statements
0 (no anxiety) 1 2 3 4 (high anxiety).
6. Picking up a math textbook to begin working on a homework assignment
0 (no anxiety) 1 2 3 4 (high anxiety)
7. Taking an examination (quiz) in a math course
0 (no anxiety) 1 2 3 4 (high anxiety).
8. Reading and interpreting graphs or charts
0 (no anxiety) 1 2 3 4 (high anxiety).
9. Signing up for a course in statistics
0 (no anxiety) 1 2 3 4 (high anxiety).
10. Waiting to get a math test returned in which you expected to do well
0 (no anxiety) 1 2 3 4 (high anxiety).
11. Being given a “pop” quiz in math class
0 (no anxiety) 1 2 3 4 (high anxiety).
12. Walking on campus and thinking about a math course
0 (no anxiety) 1 2 3 4 (high anxiety).

Appendix 9

Number Theory Pre-Questionnaire (NTPQ)

1. In general, how comfortable are you with mental calculations with 1 digit whole numbers?
 - not at all
 - very little
 - okay
 - very much
 - completely
2. In general, how comfortable are you with mental calculations with 2 digit whole numbers?
 - not at all
 - very little
 - okay
 - very much
 - completely
3. In general, how comfortable are you with reading and recall of information?
 - not at all
 - very little
 - okay
 - very much
 - completely
4. In general, how comfortable are you with reading and comprehension of information?
 - not at all
 - very little
 - okay
 - very much
 - completely
5. In general, how comfortable are you with thinking mathematically/logically?
 - not at all
 - very little
 - okay
 - very much
 - completely
6. Overall, how comfortable are you with your thinking/reasoning skills?
 - not at all
 - very little
 - okay
 - very much
 - completely

7. How comfortable are you at this time when you are informed that you are going to study a topic regarding the Division Theorem in this experiment?

- not at all
- very little
- okay
- very much
- completely

Appendix 10

Post-Test

1. 1, 2, 3, 6, 7, 14, 18, 42, are all divisors of 42
 - True
 - False
2. Please rate how confidently you believe your last answer was correct. 0 indicates 0% confidence --- 10 indicates 100% confidence
0 1 2 3 4 5 6 7 8 9 10
Answer :
3. 7 is a divisor of 42
 - True
 - False
4. Please rate how confidently you believe your last answer was correct. 0 indicates 0% confidence --- 10 indicates 100% confidence
0 1 2 3 4 5 6 7 8 9 10
Answer :
5. In the equation $42 = 2(18) + 6$, the dividend is
 - 6
 - 2
 - 42
 - 18
6. Please rate how confidently you believe your last answer was correct. 0 indicates 0% confidence --- 10 indicates 100% confidence
0 1 2 3 4 5 6 7 8 9 10
Answer :
7. For any two whole numbers A and D, A is divisible by D, and D divides A, if and only if there exists unique whole numbers Q and R such that $A = QD + R$, and R is less than D.
 - True
 - False
8. Please rate how confidently you believe your last answer was correct. 0 indicates 0% confidence --- 10 indicates 100% confidence
0 1 2 3 4 5 6 7 8 9 10
Answer :
9. A is a prime number because A is divisible by both 1 and A
 - True
 - False
10. Please rate how confidently you believe your last answer was correct. 0 indicates 0% confidence --- 10 indicates 100% confidence
0 1 2 3 4 5 6 7 8 9 10
Answer :
11. If $42 = 2(18) + 6$, then 18 is a divisor of 42

- True
 - False
12. Please rate how confidently you believe your last answer was correct. 0 indicates 0% confidence --- 10 indicates 100% confidence
0 1 2 3 4 5 6 7 8 9 10
Answer :
13. If the dividend is a multiple of the quotient, then the quotient divides the dividend.
- True
 - False
14. Please rate how confidently you believe your last answer was correct. 0 indicates 0% confidence --- 10 indicates 100% confidence
0 1 2 3 4 5 6 7 8 9 10
Answer :
15. If A is a prime number and D divides A, where D is not equal to 1, then A divides D.
- True
 - False
16. Please rate how confidently you believe your last answer was correct. 0 indicates 0% confidence --- 10 indicates 100% confidence
0 1 2 3 4 5 6 7 8 9 10
Answer :
17. A is a divisor of D, if $D = QA + R$, where R is less than A
- True
 - False
18. Please rate how confidently you believe your last answer was correct. 0 indicates 0% confidence --- 10 indicates 100% confidence
0 1 2 3 4 5 6 7 8 9 10
Answer :
19. If D divides A and R divides D, where $A = QD + R$ and R is less than D, then R divides A
- True
 - False
20. Please rate how confidently you believe your last answer was correct. 0 indicates 0% confidence --- 10 indicates 100% confidence
0 1 2 3 4 5 6 7 8 9 10
Answer :

Appendix 11

Post-Questionnaire

The following 6 questions ask about your thoughts having come to your mind during the task. Remember there are no right or wrong answers; just answer as accurately as possible.

1. Was this learning task interesting to you? 0 indicates not interesting at all --- 7 indicates very interesting

0 – 1 – 2 – 3 – 4 – 5 – 6 – 7

2. Was this learning task challenging for you? 0 indicates not challenging at all --- 7 indicates very challenging

0 – 1 – 2 – 3 – 4 – 5 – 6 – 7

3. In general I chose the items for restudy

- that were interesting to me
- that were difficult to understand
- that were easy to understand
- that were possible test questions
- for no particular reason

4. Did the shading and highlighting take your attention away from studying the material at hand?

0-not at all – 1 – 2 – 3 – 4 – 5 – 6 – 7-very much

5. To what extent did you review the item that you just labeled during your first 10-minute study?

- Always
- sometimes
- Never

Appendix 12

Learning Material (Text Version)

The Division Theorem

Let's explore a bit of the field of mathematics called **Number Theory**. We are only concerned here with **whole numbers**, that is, the **numbers beginning with 0, and progressing 1, 2, 3, ...and so on**. **Select any two whole numbers, using the letters A and D to represent whatever those two whole numbers happen to be. I have a special requirement about D, that it cannot have the value of 0**. Now, there is an important relationship I want you to try to understand: Once we **fix the number values for A and D**, then **there are only two other whole numbers, that we will call Q and R**.

Such that **A is equal to Q times D and then adding R**, so long as **R is less than D**. We can see that **Q and R are the only numbers that satisfy this relationship, because there are no other numbers once we fix the values for A and D** for which we can write $A = QD + R$. For example, **when we take A to be equal to 26 and we take D to be equal to 4, then the only two numbers that will satisfy this equation is when Q is equal to 6 and R is equal to 2**.

Let's give real "names" to A, Q, D, and R:

A is called the *dividend*.

Q is called the *quotient*.

D is called the *divisor*.

R is called the *remainder*.

Now let's look at some examples:

When A is 7 and D is 3, then Q is 2 and R is 1, since $7 = (2 \times 3) + 1$.

When A is 27 and D is 4, then Q is 6 and R is 3, since $27 = (6 \times 4) + 3$.

The Division Theorem basically boils down to the following: For **any two whole numbers A and D, where D is not equal to 0, then there will exist unique whole numbers Q and R, such that $A = QD + R$, where R is less than D**.

Divisibility Relations

Here are some other important relationships concerning whole numbers to study.

When we choose A and D, and we find Q such that $A = QD$ and R is 0, we say that "A is *divisible* by D." Also, because there is a value Q that we can multiply by D to get A, we say that "D divides A**," "**D is a factor of A**," and "**A is a multiple of D**." Now, **if D is a divisor of A, then D divides A, and if D divides A, then D is a divisor of A**. We also say that **if D divides A, then D is a factor of A and if D is a factor of A, then D divides A**,**

and that if D is not equal to A , then D is a *proper divisor* of A . *Prime numbers* have no proper divisors.

Examples:

When A is 20 and D is 2, then 2 divides 20, because $20 = 10 \times 2$.

When $A = 15$ and $D = 5$, then 5 divides 15, because $15 = 3 \times 5$.

17 is a prime number because it has no divisors aside from 1 and itself.

Appendix 13

Instruction to the Participants

First, you will have 10 minutes to study a text describing a theorem in mathematics called the Division Theorem. Please study quickly but carefully.

You will notice there are several **shaded regions** in the text. Please label **each** shaded region with your judgment of how difficult it is to learn: *not well learned*, *well learned*, or *very well learned*. To label a shaded region:

1. Click and drag across the **entire shaded region**.
2. Right-click to show the pop-up menu.
3. Move your cursor over the top “Label As ...”
4. Move your cursor over the label you choose:

Not well learned
Well learned
Very well learned

After 10 minutes have passed, you will have a 1-minute break.

Then, you will have another 10 minutes to restudy the material to learn it in depth.

When the 10-minute restudy period is over, you will take a test with 10 questions. Some questions are true-false and other questions are multiple choice.